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NRL Memorandum Report 3079

Interpretation Facility for Synthetic Aperture Radar

[Unclassified Title]

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Airborne Radar Branch
Radar Division

July 1975

NAVAL RESEARCH LABORATORY
Washington, D.C.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) NRL has developed a mini-computer based facility for collecting, processing, and displaying synthetic aperture radar (SAR) data and imagery. Data collection equipment includes an airborne wideband digital tape recorder for collecting raw SAR data and a dual-mode digitizing photometer/densitometer for digiting film-recorded data. Raw SAR data may be processed into imagery either with an optical correlator or with a digital computer. Image manipulation is under interactive control. Working imagery is displayed with a computer controlled pseudo-color TV display system.

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Memorandum

Subject: Interpretation Facility for Synthetic Aperture Radar

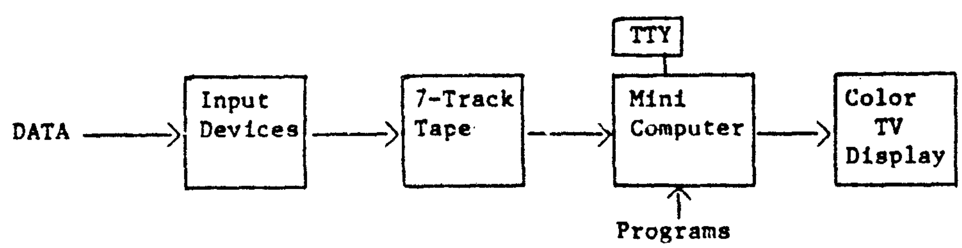
1. Background

Synthetic aperture radar (SAR) images require interpretation techniques quite different from those used for aerial photographs. Probably the most significant difference is that SAR interpreters must be trained on SAR images; the superficial resemblances between SAR images and photographs completely breaks down when the images are examined in detail. Traditionally SAR imagery has been presented to interpreters as film transparencies, produced in an optical correlator, to be viewed on a light table with a microscope. This method of presentation, however, does not fully utilize the information content of the SAR data. In particular, SAR images have far more dynamic range than can be captured on film; and because the SAR data is analogous to a hologram, it can be refocused as a part of the image formation process (called correlation). Furthermore, digital processing is used for modern high performance SAR systems; and the output of a digital processor is a number array in a computer rather than an optical image for photographing. Thus, to fully exploit the interpretation potential of SAR imagery, an image presentation facility should include digital image processing a wide dynamic range display, and hologram refocusing. In addition, a facility should have such capabilities (not unique to SAR) as selective magnification, rotation, image warping, and overlaying for comparison.

The NRL has assembled an experimental digital SAR interpretation facility. Most of the digital processing and display techniques are new and optimum application procedures have not been determined. Thus the processing and display have been made highly flexible and interactive; an interpreter can find the best processing and display procedure experimentally. Knowledge gained with this facility will allow the efficient design of operational interpretation facilities.

2. Results

The main functions of the facility are shown below



Data Forms	Film phase history Digital phase history (7-track tape) Digital phase history (14-track tape) Digital image (7-track)
Input Devices	Static optical correlator Dual mode (film and aerial image) scanner 14-track tape reformatter
Processor	NOVA-1200
Programs	DINASAR (digital correlation) HIPS (interpretation processing) Display utilities
Display	Comtal pseudo-color TV digital image display

The complete facility went into service in the summer of 1974. It is applied in several investigations which will be reported separately. The principal investigations are (1) analysis of the performance of trained interpreters using the facility, and (2) interactive digital correlations of ship phase histories to remove the effects of ship motion.

3. Research Implications

The facility was developed to assist in the solution of the unique problems associated with target classification from SAR images. In particular it has approaches for handling the enormous SAR dynamic range (pseudo-color display), SAR moving target and perspective distortions (image processing programs), SAR moving target defocusing (interactive digital correlation), and displaying digital numeric array images. Use of the facility can answer such questions as:

(a) How does an interactive TV display compare with film and a light table as a display medium for an interpreter?

(b) Does using the full SAR dynamic range enhance the classification of small targets in SAR images?

(c) Is pseudo-color a useful way to display a large dynamic range?

(d) What numerical focusing criteria are useful for obtaining classification-quality correlations on moving ships?

(e) Is there a set of focus criteria which make automatic correlation of moving ships practical?

4. Recommendations

Research to find the answers to the above questions should be continued.

The hardware and software in the facility have a great deal of flexibility to perform a wide variety of powerful processing functions. This flexibility, however, is often paid for by slow operating speed. In an interactive environment a slow operation, even though helpful in improving the interpretability of an image, may not be used because it causes too much delay in the interpretation flow. Thus, it is recommended that processing functions which are proved useful be optimized for operating speed. In some cases this will require improved software; in others it will require special hardware (e.g. FFT processors).

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INTERPRETATION FACILITY FOR SYNTHETIC APERTURE RADAR
[Unclassified Title]

1. Introduction

Improvements in synthetic aperture radar (SAR) resolution which have occurred in the last few years have made it a viable sensor for target classification/identification. Improved performance, principally in stability and motion compensation, have made resolutions of five feet commonplace, and certain special systems operate regularly with one foot resolution. While this is at least an order-of-magnitude poorer resolution than can be obtained with optical sensors, it can be obtained in all weather, day-night, and at long range (50 naut mi). The resolution of SAR is fine enough to permit classification/identification of a wide variety of militarily important targets.

Full exploitation of the classification/identification potential of SAR requires different interpretation techniques than are currently used for either SAR area maps or optical photographic imagery. SAR images differ qualitatively from photographic images for reasons other than resolution. The illuminating wavelength is different (3 cm typical SAR vs 500 nm optical). The images are made with coherent radiation, leading to enormous dynamic ranges, specularity, and target break-up. A target is imaged in the range and cross-range dimensions (distance-distance) by SAR as opposed to the azimuth-elevation (angle-angle) dimensions of optical imagery, leading to significant differences in perspective. The SAR images are analogous to holograms recorded over aperture times of 0.1 to 10 seconds. The aperture times are much longer than photographic shutter-speeds and thus lead to much more serious target motion effects; however the hologram nature of the recorded data allows for a considerable amount of refocusing to remove motion effects during SAR processing. These unique problems of SAR imagery make it impossible, at least at present, to produce by a non-adaptive process a best image or even a series of images as good as photographic transparencies which provide all the possible classification information to an interpreter.

The facility to be described in this report was developed for experimenting with and demonstrating the necessary new SAR interpretation techniques. The facility permits an operator to interact with the imaging process at all stages, from correlation through final display. Hopefully, these interactions will permit the generation and display of images which present the full target classification information to the radar interpreter. To make the interactive techniques flexible and applicable to modern processors, most of the implementations in the facility use digital computing techniques.

Note: Manuscript submitted June 20, 1975.

The need for interactive correlation (processing SAR phase histories to images is called "correlation") has been generated by the requirement to develop classification quality SAR images of ships at sea. Movement of the ship (roll, pitch, yaw, heave, surge, sway) distort the azimuth hologram, producing blurring and distortion in the image. Because the data are in the form of a hologram, much of the blurring can be removed by refocusing during correlation. However, the ship's motion produces differential velocities and accelerations between different portions of the ship's structure, requiring different focusing corrections for different portions of the ship. The interactive feature of the facility allows the operator to use different processing functions for different portions of the ship to improve the quality of the overall image.

It is also, and even principally intended that the operator, by noting how the imagery reacts to different processing functions, will gain insight into methods for mechanizing the selection of processing functions, i.e. to develop an "adaptive" processor for ship images. This portion of the facility will serve as a test-bed for adaptive techniques.

The manipulation of images in the interpretation facility is performed to make it easier to classify, identify, sort, or to recognize certain features in the imagery. It will be recognized during the detailed descriptions of the available manipulations that the presentation or display of a large dynamic range has received a lot of attention. This problem has been attacked in two general ways, (1) by shaping of the signal-amplitude-to-display-brilliance curve, and by (2) the use of color to represent signal amplitude. These schemes are intended to allow the display of a larger dynamic range than could be displayed on film or a normal CRT, the more normal display media. The need to display more than the usual 20 dB has become apparent in a number of programs, Project RICE at NRL being one of these programs.

Another feature of the manipulations that has received considerable effort is associated with the "stretching" or "warping" of two or more images of the same scene, but obtained from different azimuth angles or on different days. This process allows registration for non-coherent integration of several images of the same scene. It allows changes which have occurred between days to become immediately apparent.

These, and many other features of the image manipulations available in the interpretation facility, will be described in more detail later in this report.

2. Overall Description of the Facility

2.1 Data Flow

The major components and data flow in the facility are indicated in the block diagram of Fig. 1. There are two types of data, phase histories and images. The phase histories may be supplied as recordings on film, high-density 14-track instrumentation tape from the airborne recorder, or 7-track computer tape. Phase histories are correlated to images and displayed. To aid in describing the general capabilities of the system, each of these inputs will be traced through the system to its display.

2.1.1 Film Phase History

A film phase history may be directly correlated in the static optical correlator, or scanned and digitized to be correlated in the Nova computer with the DINASAR programs. If the optical correlator is used, the first intermediate output is an aerial image formed of laser light in the output slit. This aerial image may be viewed through a microscope, photographed, displayed on closed circuit TV, or scanned, digitized, and recorded on tape by the dual-mode scanner. If the static optical correlator is not used, the phase history film is converted to a digital phase history on tape by the dual-mode scanner operating in the film mode.

2.1.2 Digitized Images

Images are input via 7-track magnetic tape and displayed on the Comtal color TV display under the control of the Nova 1200 and its programs. The combination of the computer and the Comtal can perform a variety of manipulations, e.g., magnify, rotate, shear, superimpose over other images, and change dynamic range response via scaling and pseudo-color.

2.1.3 Digitized Phase Histories

Digital phase histories are also input via 7-track tape. These may come from sources outside NRL, scans of film phase histories by the dual-mode scanner, or from reformatting the 14-track instrumentation tape produced by the airborne recorder. The phase histories are correlated (processed to images) in the Nova using the DINASAR computer programs under either automatic or interactive operator control. Completed images may be directly displayed on the Comtal or recorded on 7-track tape for later display.

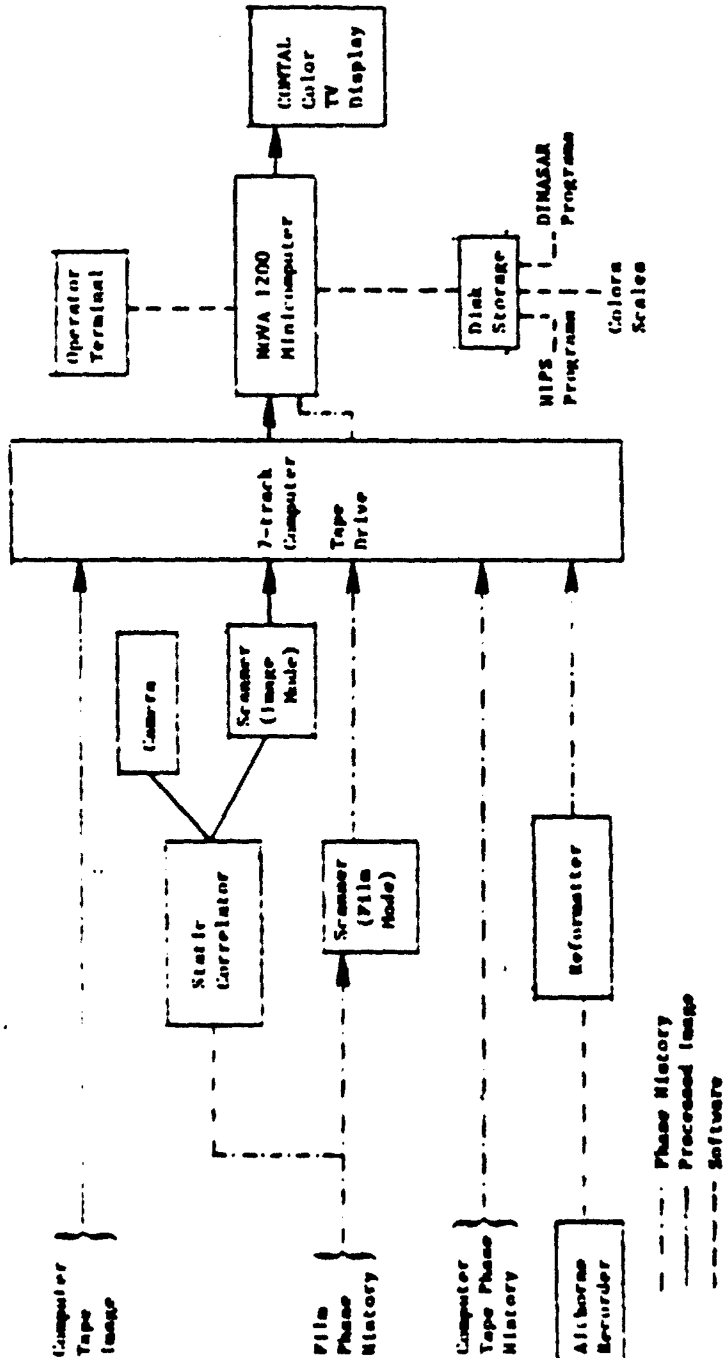

Fig. 1 Digital SAR interpretation and processing facility

2.2 Major Components

2.2.1 Data Processing and Control

All digital processing is performed by a Data General Nova 1200 mini-computer. Some of its options and peripherals are listed in Table I. The Nova 1200 is a 16 bit machine with a memory cycle time of 1200 ns. The equipment and software listed in Table I provide a very flexible and powerful experimental processing facility. It should be noted, however, that the flexibility extracts a penalty in processing time; almost any function programmed for the Nova could be performed much faster by a hardwired special purpose processor. Since the computer and its peripherals are all standard catalog equipment, no detailed description of it will be presented here.

2.2.2 Airborne Recorder and Reformatter

Digital SAR correlation requires digital phase histories for input. Digital phase histories can be produced by scanning and digitizing film phase histories; however, there are opportunities for a number of distortions and degradations in the process which leave in doubt the quality of the resulting data. To overcome this, NRL sponsored the development of an airborne SAR recorder at Goodyear Aerospace Corporation.

The equipment is in two units. A flight-qualified airborne unit accepts wideband IF from the SAR and produces a 14-track, high-density, Miller-encoded instrumentation tape recording of the phase history. A ground based reformatter plays back the high-density tape and, using the Nova computer, reformats the data onto computer compatible 7-track tape.

The operation of the recorder-reformatter will be described in Section 3.1.

2.2.3 Static Optical Correlator

During Project RICE NRL obtained a static optical correlator. This instrument is designed to process a small portion of a film SAR phase history into a finely focused image. There is a great deal of flexibility in the azimuth focusing function to allow compensation for the defocusing caused by the motion of ship targets. Figure 2 is a photograph of the static correlator. Its output is an aerial image of laser light. In Project RICE this image was viewed through a microscope or photographed. The range of intensities in the laser light image is too large (over 45 dB) to photograph successfully. The full dynamic range contains information essential to full exploitation of an image

Table I

COMPUTING EQUIPMENT

CPU	Nova 1200
Core storage	32K 16b words
Computing options	Hardware multiply/divide Floating-point processor
Data storage	3.5 M. words disk cartridge 12.5 M words disk pack 7-track tape
Operating systems	Data General RDOS Xebec XDOS
Programming languages	Nova Assembly Fortran IV Fortran 5 Basic
Human interface	Teletype ASR-33 Infoton CRT terminal Versatec electrostatic printer/plotter

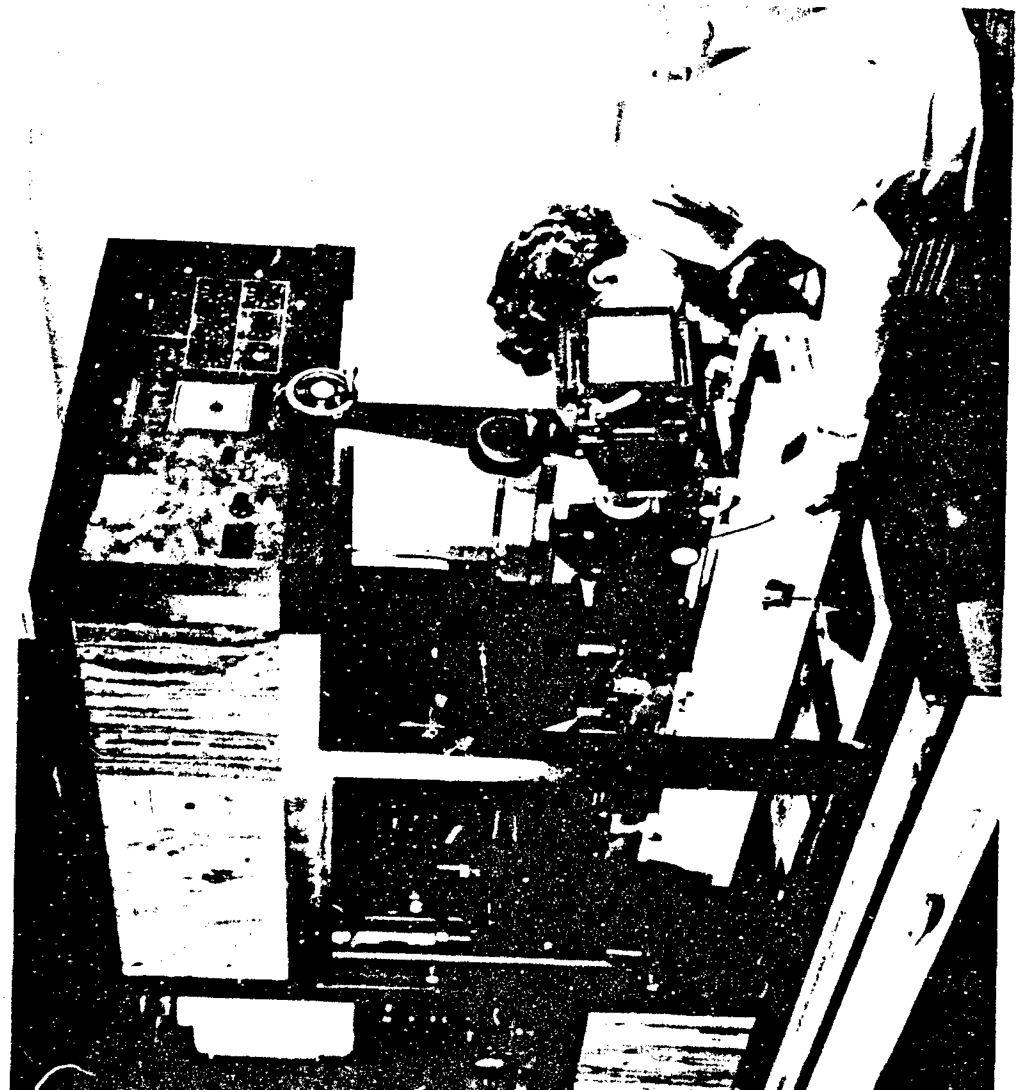

Fig. 2 — Static optical correlator

by an interpreter, and the interpreter needs a permanent copy for mensuration, comparison with other data, and for developing a library.

2.2.4 Dual Mode Scanner

The NRL sponsored the development of the dual-mode scanner at Perkin-Elmer to (1) scan and digitize film phase histories for digital correlation processing, and (2) to scan and digitize the laser light aerial images in the static correlator to produce a permanent image record with the full dynamic range, suited to further digital image processing. The scanner uses the same scanning head, control and data electronics, and recorder for both functions. The detailed operation of the dual mode scanner will be described in Section 3.2.

2.2.5 Display

Output images are displayed on the Comtal pseudo-color TV display. This device accepts from the Nova and stores in its refresh memory, two eight-bit 512 x 512 pixel images. It maps each of the 256 levels of input data into one of 64 colors for display on a TV monitor. The amplitude-to-color mapping is completely under computer control. The operation of the Comtal will be described in detail in Section 3.2.

2.2.6 Applications Programs

There are three principal sets of applications computer programs used with the system. The HIPS (Hybrid Image Processing System) programs manipulate the dynamic range and geometry of SAR images to enhance their interpretibility. The DINASAR (Digital Interactive SAR) programs digitally correlate SAR phase histories under the interactive control of an operator. The interactive capability is designed to allow correction for ship-motion effects. The COLORS and SCALES programs place the amplitude-to-color mapping functions of the Comtal under the direct control of an operator using the keyboard of the terminal and the trackball.

3. Detailed Operation of System

Those portions of the facility which are unique and which have not been described elsewhere will be described in detail in this section.

3.1 SAR Digital Recorder

3.1.1 General Characteristics

The total recording subsystem, including both the airborne and ground portions, can be broken down in the following manner:

Airborne - Data conversion, bandwidth compression buffer, reformatting and encoding, high speed tape recorder.

Ground - Playback recorder and electronics, squaring and bit synchronizing deskewing buffer, reformatting circuitry, editing station (mini-computer and tape handler).

Some of the characteristics of the SAR recording system are listed in Table II.

3.1.2 Airborne Recorder

Data Conversion Subsystem

Radar signals are fed into the recorder at IF along with a coherent reference signal. The synchronous demodulator converts these inputs into in-phase and quadrature (I and Q) video signals. There are two demodulator units and four A/D converters, making possible the conversion of signals obtained from those radars capable of receiving dual polarization signals. Figure 3 shows the signal flow for one of the 12 data lines actually utilized in the system. Since all the data channels perform identical functions, an explanation for any one will suffice for all.

The output of the demodulator is fed through a highspeed A/D converter which digitizes at a rate of 100 MHz. The gated clock which actuates this unit is initialized from the radar sweep trigger used to synchronize the optical recorders normally used with the SAR. The signals are sampled at a 100 MHz rate which enables the system to resolve an upper frequency of 50 MHz. By utilizing both the in-phase and quadrature signals in the processing functions, the system bandwidth becomes 100 MHz.

Bandwidth Compression Buffer

The wide-band digital signal produced in the A/D units is bandwidth-compressed and buffered to reduce the bandwidth required of the high speed tape recorder from 100 to 2.8 MHz. This buffer consists of 12 lines, each line one bit wide and up to 8192 bits long. Minor hardware changes to the buffer and converter units permit the grouping of lines which produce the recorder characteristics shown in Fig. 4. As can be seen on this chart, tradeoffs can be made among bits-per-sample, range swath, and number of channels. Also, a lower radar PRF allows more area to be covered by the digital recorder swath. The real limitation is in the 2.8 MHz bandwidth of the 14-track instrumentation recorder.

TABLE II

CHARACTERISTICS OF SAR RECORDING SYSTEM

Number of data channels	1 or 2 complex
Sample rate per channel	10^8 samples/second
Sample precision	3 bits or 1 bit
Range Swath	2200 complex samples at 2000 pps
Recording time	15 min
Design error rate	10^{-4}
Recording medium	14 track magnetic tape
Recording density	23.3K bpi
Interface to processors	7-track computer magnetic tape produced by ground playback unit

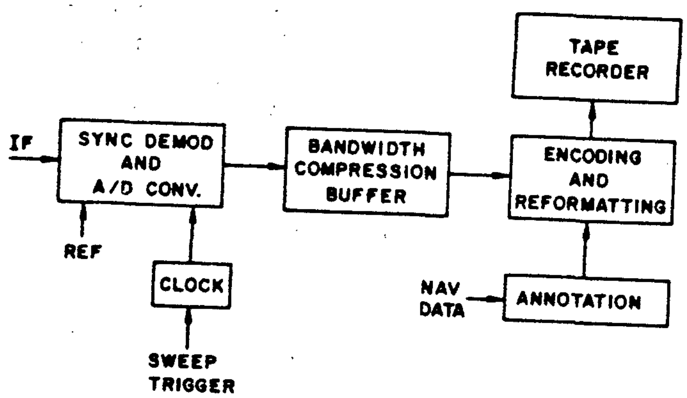

Fig. 3 — Airborne recorder system

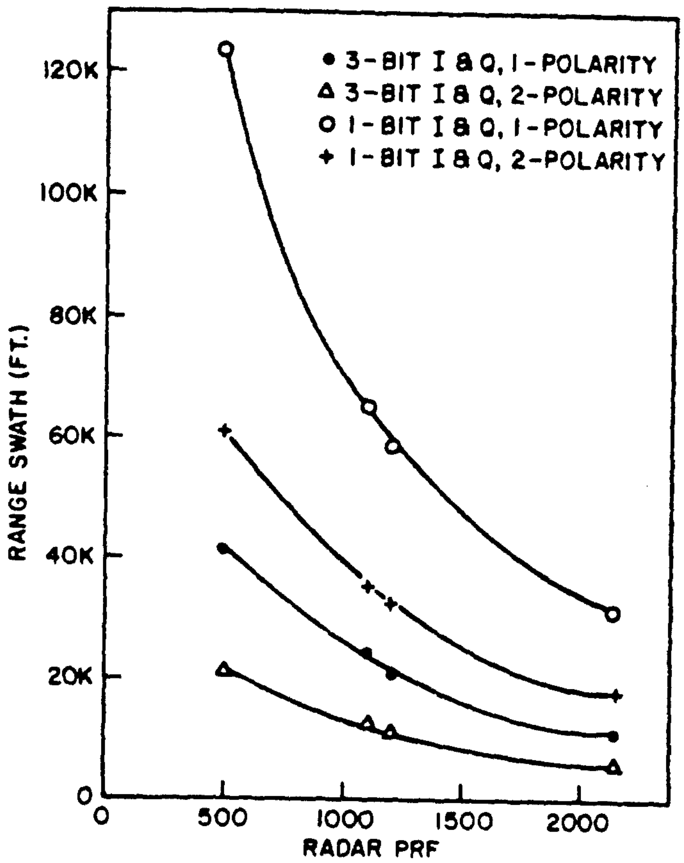

Fig. 4 — Available swath widths

Formating

The formating buffer accepts the digital information from the bandwidth compression buffer, performs a parallel-to-serial conversion, and delivers the results to the encoding electronics. In addition, it records a header on each track for each range swath, puts a synchronizing pulse on track number one, and records annotation information on track fourteen. Because of a corner-turning operation, all data from any particular I or Q sample will be recorded on a single track. In this way, the loss of a recorder channel would not have as much effect on the overall results as if the bits were laid down in parallel fashion. The track assignments for the three-bit, two-channel configuration are shown in Table III.

14-Track Recorder and Electronics

Fourteen data lines from the formating buffer are applied to the tape electronics. These data are Miller encoded to facilitate the extremely high packing densities required to make this system practical. The recorder is an Astro Science (Bell and Howell) MC-14E model. Its upper bandwidth limit is 2.8 MHz and when operated in the high speed mode of 120 inches (ips), each track is packed at approximately 22K bits/inch. Since packing density, recorded swath width, and recording time are directly related, it is desirable to pack the tape as densely as possible and still r tain a reliable overall system. Recorder endurance time, when running at 120 ips, is 15 minutes. Since each reel has a limited recording time, and because the radar systems involved do not allow for changing reels in flight, the tape drive is turned on and off so that only targets of interest are recorded.

Figures 5a and 5b are photos of the airborne portion of the system.

3.1.3 Ground System

Figure 6 is a simplified block diagram of the ground system showing only one of the 12 radar data channels, since all channels incorporate identical operations. This system provides computer compatible tapes which are subsequently used as inputs for digital correlation. Figures 7a and 7b are photographs of the ground installation.

Playback Recorder and Electronics

The recorder used to recover the in-flight data is an MC-14E machine, identical to the one used in the airborne portion of the system. This feature of redundency was designed into the system to minimize

TABLE III

RECORDER TRACK ASSIGNMENTS

Track #	
1.	PRF sync pulse
2.	I data, characters 1,7,13, ...
3.	Q data, characters 1,7,13, ...
4.	I data, characters 2,8,14, ...
5.	Q data, characters 2,8,14, ...
6.	I data, characters 3,9,15, ...
7.	Q data, characters 3,9,15, ...
8.	I data, characters 4,10,16, ...
9.	Q data, characters 4,10,16, ...
10.	I data, characters 5,11,17, ...
11.	Q data, characters 5,11,17, ...
12.	I data, characters 6,12,18, ...
13.	Q data, characters 6,12,18, ...
14.	Annotation data

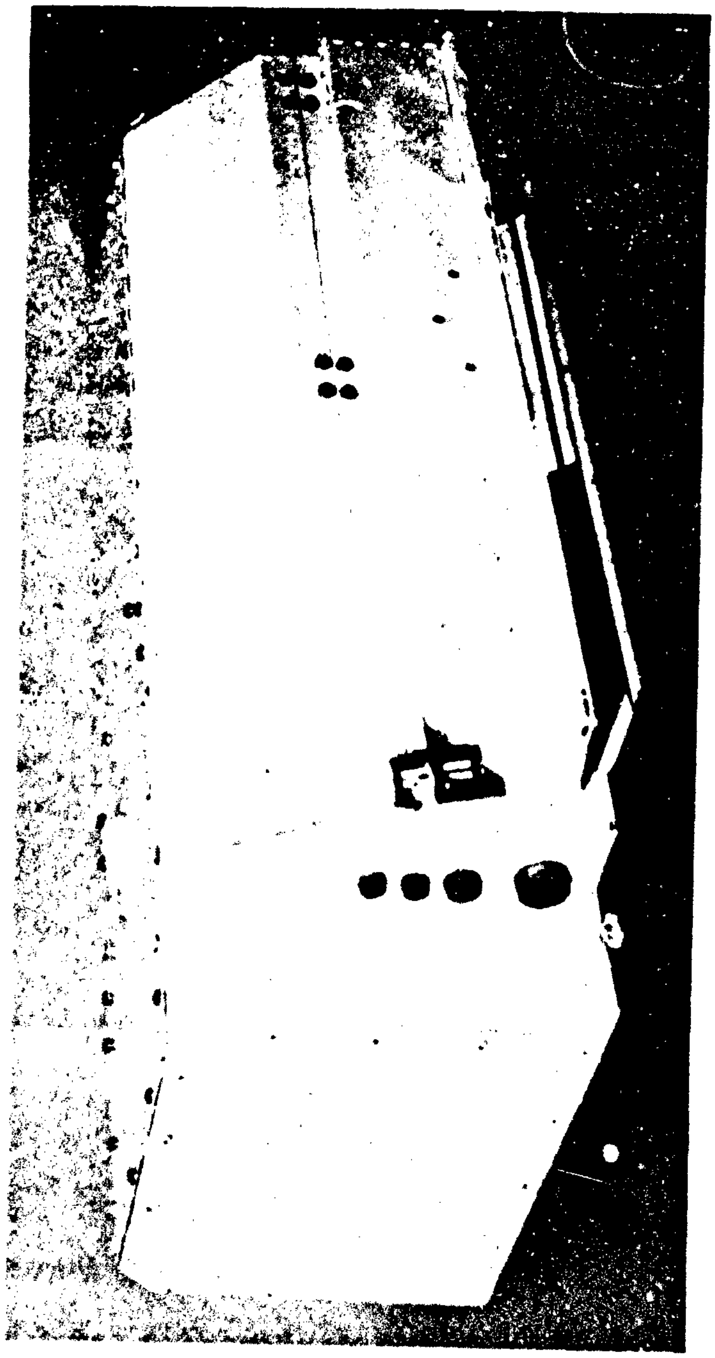

Fig. 5(a) — Airborne recorder

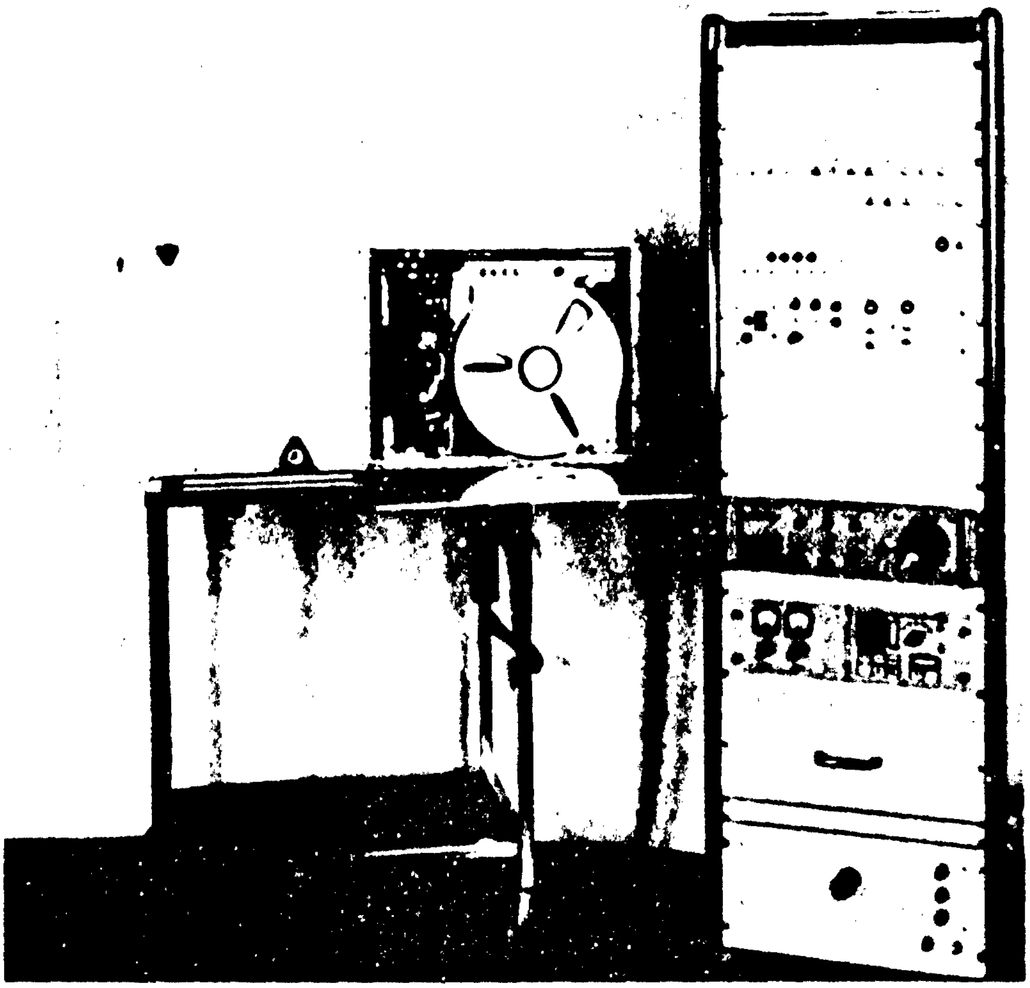

Fig. 5(b) — Airborne recorder

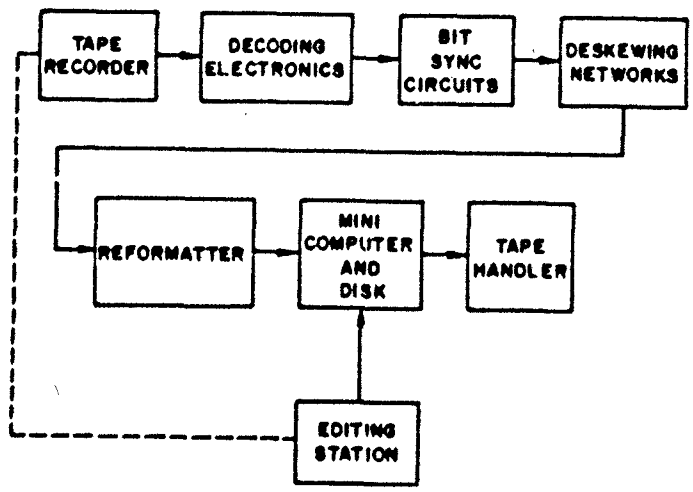

Fig. 6 — Ground reformating system

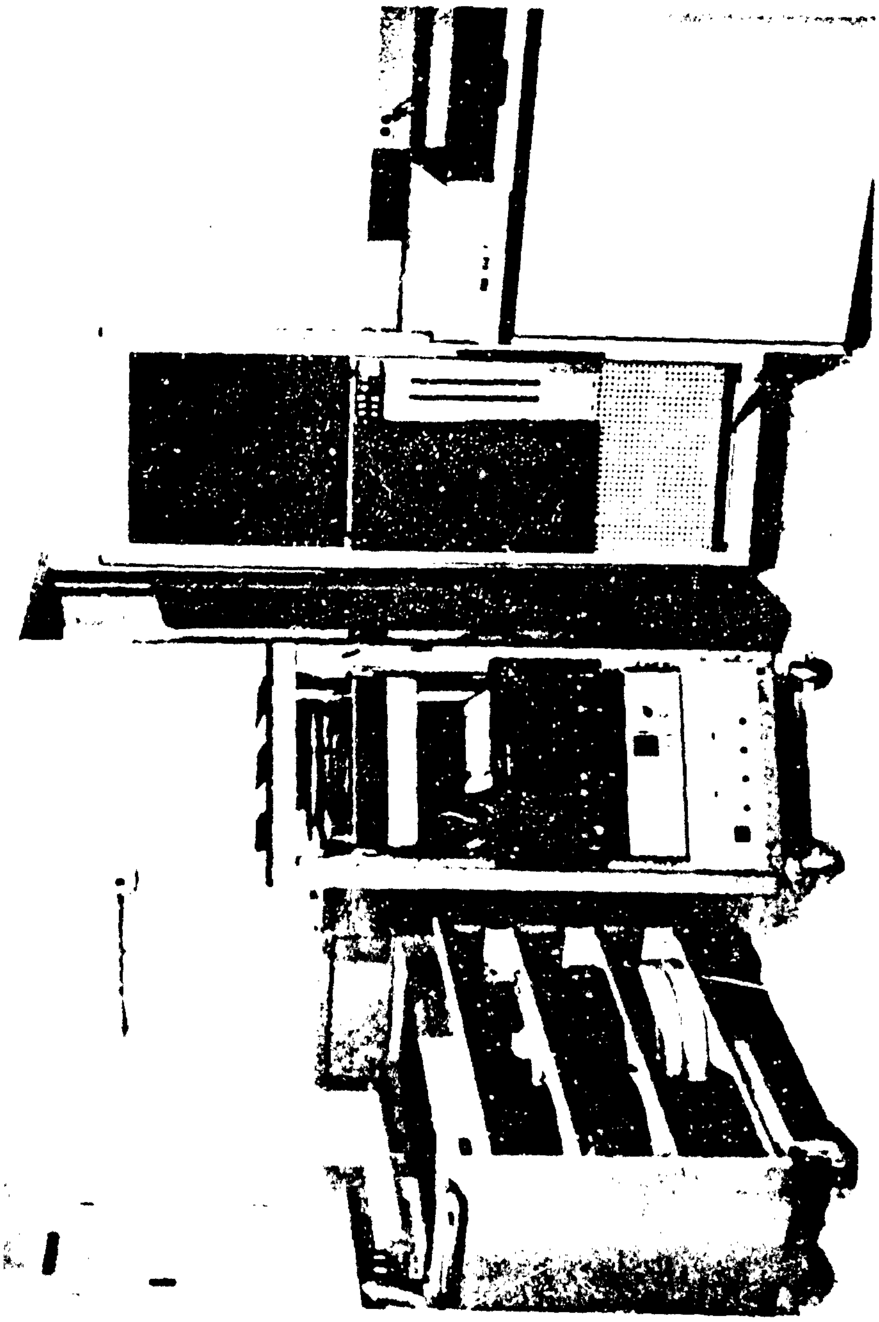

Fig. 7(a) — Ground system photo

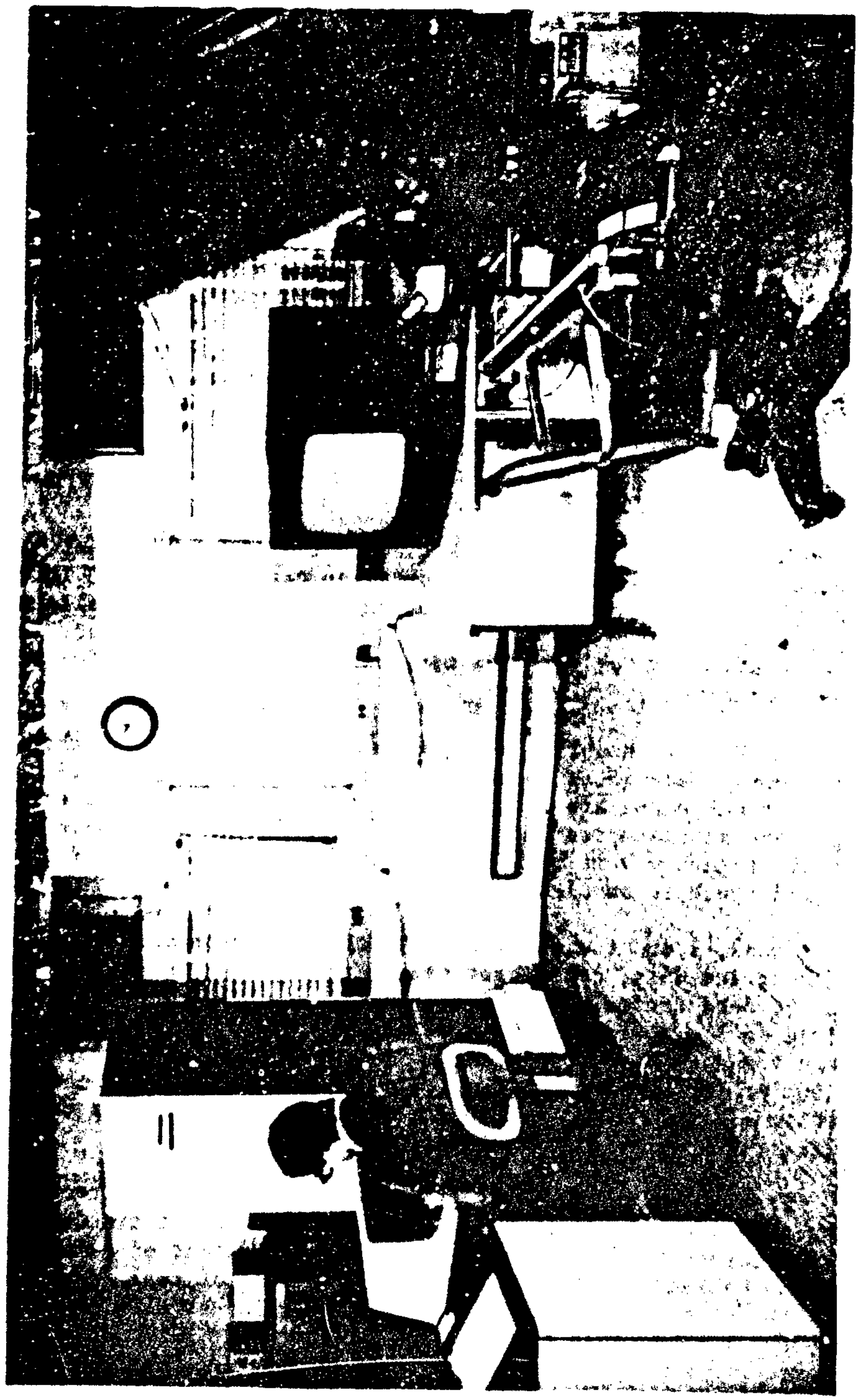

Fig. 7(b) — Ground system photo

the amount of skew introduced by recorder differences, and also to provide a spare airborne recording unit in cases of emergencies. This recorder is used in the 1 7/8 ips modes 1/64th the speed of the airborne machine. The speed reduction helps match the data rate from the high density tape to that which can be recorded on the 7-track computer tape. The computer ta:a runs at a maximum of 120 ips and is packed at 556 bits per inch.

The system utilizes a separate wideband electronics amplifier for each of the 14 channels. The reproduce amplifier provides amplitude and phase equalization for the overall direct record/reproduce system and contains gain controls and equalization circuits for tape speeds of 1 7/8 and 3 3/4 ips. Also in the control box along with the amplifiers, are the tape transport control switches for stop, start, record, fast wind, and fast rewind.

Squaring and Bit Synchronization

The data from the playback electronics is an AC signal which has been phase compensated and adjusted in gain. It is fed into a squaring circuit, with a DC restoration network which establishes a zero cross-over point for each signal. It is then amplified, limited to TTL levels, and fed into the bit synchronizer circuits for clock and data generation.

The bit synchronizer recovers a clock which runs at the (64:1 slowed down) fundamental frequency of the data recorded in-flight. Data and clock edges are strobed to a phase comparator, and error signals are generated to vary a voltage-controlled monostable multivibrator frequency. At the proper transitions, the phase of the generated clock is sampled and corrected if necessary.

Tracks 1 and 14, which contain the PRF synchronizing pulse and the annotation data, do not get passed through the deskewing buffers as do the data channels. The synchronizing pulse from track 1 is utilized in a number of areas in the ground system to provide continuity between the airborne and the ground reformated data. The annotation data out of the bit synchronizer circuitry, after being decoded, is stored in a buffer, and is passed along to the computer as the last 96 bits of information in each data block.

Tracks 2 through 13 are fed to a data selector, after bit synchronization, and if required, up to 88 bits of static deskewing can be incorporated. Also at this point, the output of a test-bit board can be fed into the data stream, in place of real data, to verify the operation of all circuitry from the deskweing buffers to the computer compatible tape handler.

Deskewing Buffer

The deskewing storage registers allow for the compensation of up to 24 bits of dynamic skew which might be introduced into the system prior to this point. The unit operates on the principle that no data will be passed on from the buffer to the reformating circuitry until the first bits of information on all channels are time synchronized. If one or more tracks contain more than the 24 bits of skew, they will be considered to have failed and a fail pulse is generated which will allow the good data to be moved downstream in the system.

Editing Station

The parallel output data which are fed from the reformater to the IO interface board of the Nova mini-computer is under control of a data editing station. This editing feature is important because each computer compatible tape has an approximate maximum recording time of only seven minutes, with a range swath of 2000 ft. Since the playback MC-14E recorder is slowed down 64:1 compared to the airborne system and has a range swath of 11,000 ft, each data tape requires approximately 88 hours to reproduce completely. This would amount to over 750 reels of computer tape from each 15 minute flight. For this reason, the full range swath is fed out of the computer through a 3 bit D/A converter, and viewed on a storage scope. When targets of interest are sighted, the wide band tape is marked, and the computer is programmed to send data to the tape handler for recording. Also, as a portion of this edit station, selected portions of the annotation, such as latitude, longitude, time, and heading, can be continuously viewed on a display monitor. This aids immeasurably in locating known targets. A high speed printer/plotter is also available, under control of the computer, for reading out complete selected data blocks either directly from the computer storage buffers, or back from the computer compatible tape handler.

3.2 Dual Mode Scanner

The Dual Mode Scanner (DMS) is designed to scan either the output slit of the static optical correlator (Mode I) or film phase histories (Mode II). This section briefly describes the equipment, its operation, and tests conducted at NRL to verify and quantify its performance.

3.2.1 General Description

The DMS has three major assemblies, designated A, B, and C.

A. Scanning Head

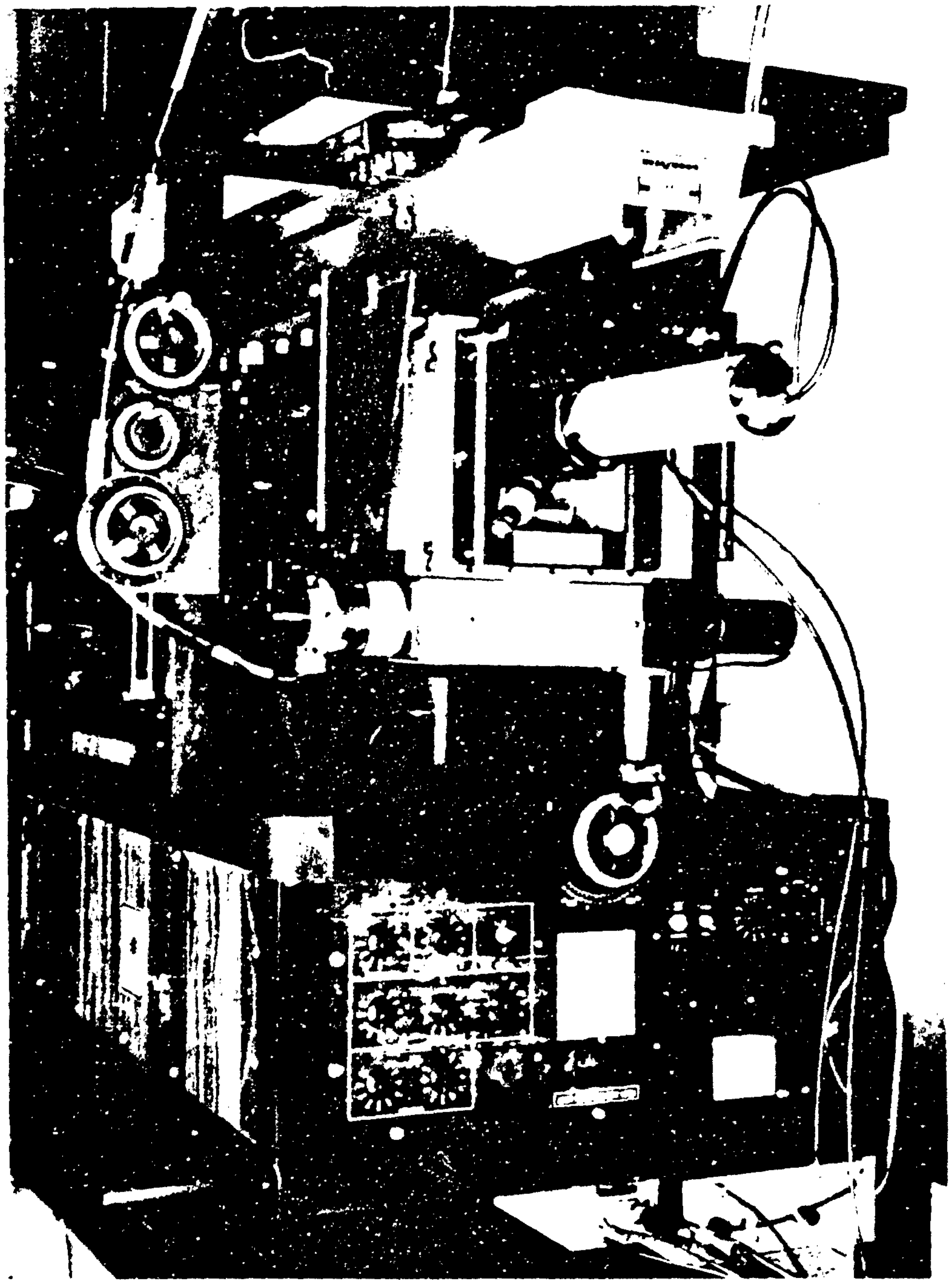

Fig. 8 — DMS scanning head positioned for aerial image scanning

B. Film Holder Assembly

C. Electronic Assemblies

Figure 8 shows Assembly A positioned on the static optical correlator for scanning an aerial image in Mode I. Figure 9 shows Assembly A positioned on Assembly B for scanning a phase history film. The electronics assemblies are in the rack.

Assembly A contains a two-axis translation stage, the photo multiplier tube (PMT), the system aperture stop, aerial image optics, film image optics, and viewing optics (with locating reticle). In Mode I, it mounts directly on the optical bench of the static correlator. In Mode II, it mounts on the film holder and illumination unit, Assembly B.

Assembly B consists of a base, an illumination assembly with lamp and projection optics, a platen, and film spools with winding cranks.

Assembly C, the electronics assemblies, consists of all the major electronics including the magnetic tape drive and controller, the translation stage drive electronics, lamp power supply, and PMT high voltage power supply, installed in a rack with the system controller which contains the DMS supervisory controls. Remote to the rack are the hand held manual controller, PMT preamplifier housing, and A/D converter.

Precise scanning motion is provided by a numerically controlled machinists' X, Y stage. The X, Y stage carries an optical assembly consisting of a pinhole in the image plane of a microscope objective lens. Light passing through the pinhold controls the output current of the PMT. A knob-movable diagonal mirror can be placed in the light path between the objective lens and the pinhold to direct the light into a microscope eyepiece to allow finding and previewing the image before scanning.

The X, Y stage is driven by digitally controlled servo motors. Its position is monitored by shaft encoders. The stage electronics can position the optical assembly with a nominal precision of 0.0001" in steps of 0.0001".

A scan is accomplished as the DMS controller sends a series of X and Y command pulses to the scanner electronics. Each pulse commands a motion of 0.0001". The command pulses come from a clock in the DMS controller whose rate controls the scan speed. The scan raster is set by digi-switches on the front panel of the DMS controller which sets the number and sequence of X and Y command and direction pulses.

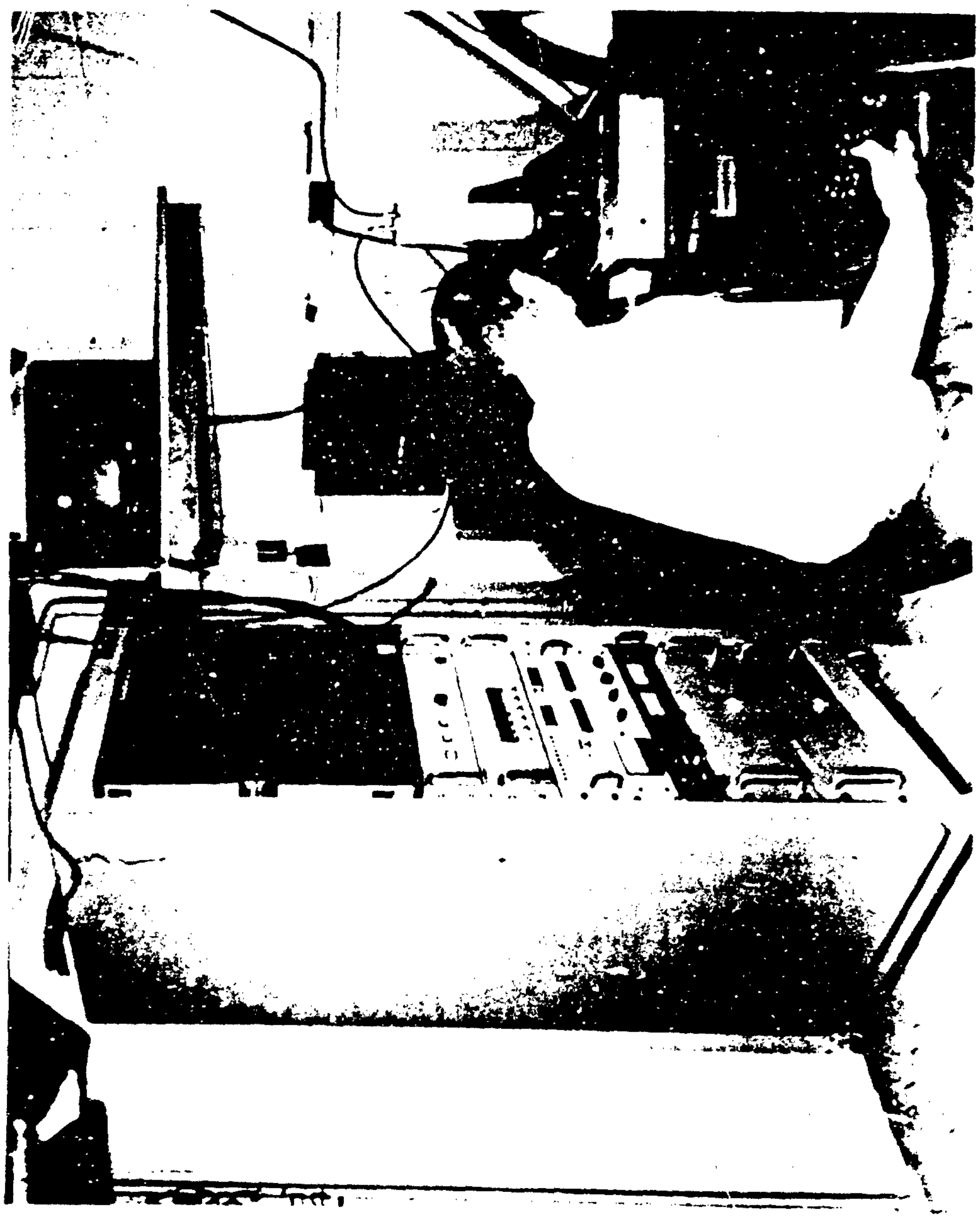

Fig. 9 — DMS control unit and scanning head positioned for film scanning

There is also a manual scan mode in which the command pulses are controlled by a hand-held control box. This box allows setting the scanner position at either a fast or a slow slew rate, or a single 0.0001" step at a time.

Pulses from the position encoders on the X, Y stage allow the DMS controller to keep track of where the scanner is at any instant. The controller sends encode command pulses to the data A:D converter at equal increments of scan positions (switch selectable to either 0.0005" or 0.0010").

The output current of the PMT is either logarithmically or linearly (switch selectable) amplified and digitized in a 10-bit A:D converter whenever command encode pulses are received from the controller. The digitized samples are NRZI encoded and recorded on 7-track computer tape.

3.2.2 Performance of the DMS

The specifications of the DMS are listed in Table IV. Some of the critical specifications were verified by tests at NRL. Summaries of the results are given here.

Mechanical Repeatability of X, Y, Positions

Forward and backward scans were made across a razor blade edge. The X, Y coordinates of the scan at which the PMT "saw" the edge were noted. The positions were found to be repeatable to within 0.0001" resolution of the system.

Full Scan Position Repeatability

The cross hairs of the scanner eyepiece were positioned over a point on a test target. The X, Y position display readouts were zeroed at that point. Using the manual controller, the scanner was moved in an arbitrary path in X and Y and then back to the same point as determined by the eyepiece crosshairs. The X, Y position displays were found to be within 0.0002" of the starting values. This indicates that backlash and other errors do not exceed 0.0002".

Evaluation of DMS Spot Size

The effective spot size for the scanner was determined by scanning over a razor blade set at an angle to the scan direction. A plot of the PMT output as the scanner moved over the edge showed that the effective spot size was 0.00054", to be compared to the 0.0005" specified.

Table IV - Dual Mode Scanner Specifications

Item	Mode I	Mode II
	Laser illumination of aerial image	Incandescent bulb illumination of film image
Scanned field (nom.)	0. 10 in. x 0.10 in.	3.0 in x 0.50 in.
Total field (travel limited)	(X) 3.75" x (y) 2.45"	
Eyepiece field (approx.) 10X	0.80 in., dia	0.80 in., dia.
Scanning spot size	0.0010 in., dia.	0.0005 in., dia.
Scan accuracy (element-to-element)	0.0002 in.	0.0002 in.
Position repeatability over total field	0.0002 in.	0.0002 in.
Scan accuracy (element-to-element)	0.0001 in.	0.0001 in.
Scan sample precision (line-to-line)	0.0001 in.	0.0001 in.
Dynamic range	45 dB	10^3
Intensity response	logarithmic	linear
Recording quantization	10 bit	10 bit
Recording format	7 track magnetic	7 track magnetic
Scan format	100 x 100	6,000 x 1,000
Scan pattern	bi-directional stepped raster	bi-directional stepped raster
Position display	element number and line number	element number and line number
Focus adjustment range	0.5 in.	0.5 in.
Parallelism - scan plan/ object plane	± 6 mrad (2 axes) fixed	± 1 mrad (2 axes) fixed
Frame time	.1" x .1" 1 minute	Fast .26" x 3" 2 hrs. Slow .15" x .15" 10 min.
Operating environment	Laboratory	Laboratory

Total System Response

In both the film and aerial image scanning modes it is important that the optical resolution and intensity dynamic range be known. The spot size described above determines the static resolution of the scanner. If, however, the bandwidth of the electronic circuitry between the PMT and the digitizer is not at least the reciprocal of the time spacing between samples, resolution detail will be lost. The bandwidth is affected by changes in dynamic range.

The output current of the PMT is converted to voltage, amplified to a value between zero and 10 volts, and digitized to 10 bits, i.e., each digitizing step is approximately 10 mv. The amplification may be logrithmic or linear (switch selectable). When the linear mode is used, a dark current correction is subtracted from the input to the amplifier, and the signal is amplified. The light sensitivity of the system is set by a combination of PMT voltage and input amplifier gain. The logarithmic amplifier accepts a current between 1 na and 1 ma to produce an output between zero and 6 v to be applied to the D:A, i.e., 6 decades at 1 v/decade. When the dark current is properly adjusted and no amplifiers are allowed to saturate, the linear mode should have a dynamic range of 1:1000, i.e., 30 dB. The logarithmic mode should have a range of 1:1,000,000, i.e., 60 dB.

As the gain of the amplifier in the linear mode increases, the bandwidth decreases -- the gain-bandwidth product was measured to be about 5×10^{10} (v/a) (Hz). As supplied, the scanner had two speeds, 3.6 and 0.45 ms/sample, requiring 280 and 2220 Hz of bandwidth, respectively. This leads to maximum usable gains of 1.8×10^8 and 2.2×10^7 respectively. Gain settings selectable by switch are 10^{10}, 10^9, 10^8, 10^7, 10^6, and 10^5. The highest two settings are useless in the slow mode, and the highest three are useless in the fast mode.

For the logarithmic mode, bandwidth is not only difficult to define, it also varies with input signal level. The minimum input current to the logarithmic amplifier is 10^{-9} a. The bandwidth at this signal level is about 80 Hz. At 10^{-8} a the bandwidth is 150 Hz, and it rises sharply after that.

In order to allow both high sensitivity and high resolution, a new, slower scanning mode of 7 ms/sample was provided, requiring an amplifier bandwidth of at least 140 Hz.

Measurements of dynamic range were made for both the logarithmic and linear operating modes. In the linear mode the dynamic range was approximately the 30 dB expected from the 10 bits. In the logarithmic

mode, using a high (1800 v) PMT voltage, about 45 dB of dynamic range was measured. If a brighter light source had been available this range might have been extended upward.

3.3 Digital Correlation

The programs to perform digital SAR correlations on the Nova, referred to as DINASAR (Digital Interactive SAR) were developed for NRL by Westinghouse under contract N00014-74-C-0018. The DINASAR programs form a complete system for inputting phase histories (raw radar data) from 7-track computer tape, preprocessing it, doing correlations (forming SAR images) in both range and azimuth, and outputting the resulting image to either 7-track computer tape or to the Comtal digital image display. The degree of interaction ranges from full operator monitoring and control of each processing stage to fully automatic unattended overnight processing.

3.3.1 Processing Flow

Figure 10 shows the functional steps in processing a SAR phase history to an image. The immediate data source is always 7-track computer magnetic tape (which may come from some outside source), the airborne recorder reformater, or the dual mode scanner. The doppler spectrum is then analyzed to determine its bandwidth and frequency offset. Those parameters are input to the prefiltering process which shapes a filter to pass only the doppler bandwidth required to provide the azimuth resolution, shifts the offset spectrum to be centered on zero frequency, and downsamples the data to the minimum sampling rate required to reproduce the filtered azimuth spectrum. The prefiltered data is then range correlated (compressed in range). Through the range correlation step, the data have been organized as successive records sampled in the range direction. Before azimuth correlation, the data must be organized as records sampled in the azimuth direction. This requires transposing or corner-turning the range-compressed data array. After corner-turn, the azimuth compression forms a final image array which may be immediately displayed, saved on tape, or both.

3.3.2 DINASAR Implementation

It was indended that DINASAR would be (1) able to correlate SAR phase histories, (2) interactive, and (3) suited for use as a test bed for automatic focusing experiments. When it was designed it was not known precisely what form of interaction was most useful, or how automatic focusing would be implemented. Modularity was therefore the keyword in the implementation. Independent programs were written to handle I/O, file management, data processing, and display. By

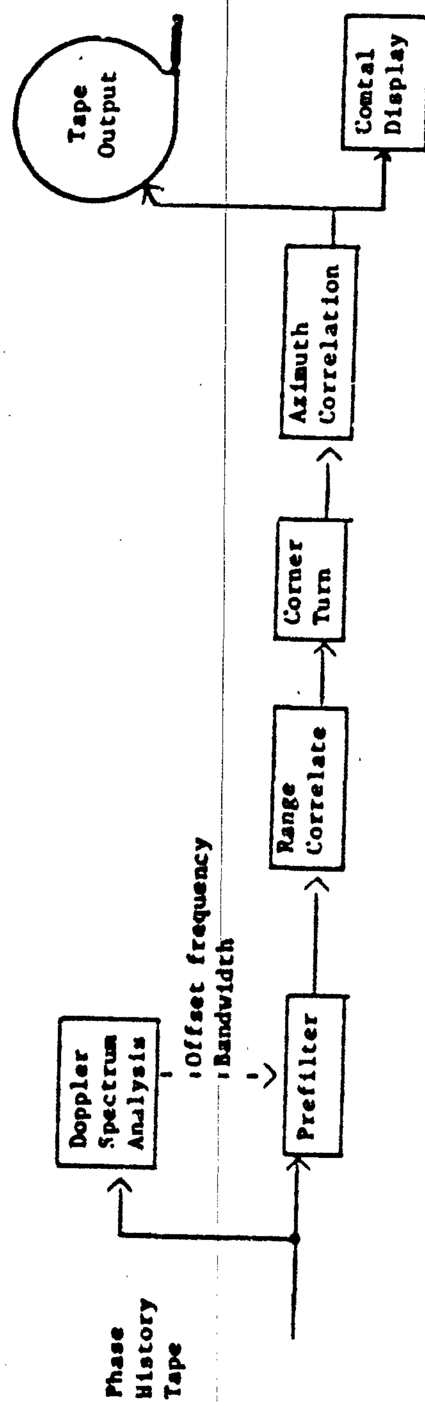

Fig. 10 — DINASAR processing flow

changing the sequence of programs and writing simple programs for changing input parameters, an almost unlimited processing flexibility was provided.

The program organization is shown in Figure 11. The program "DINASAR" creates the file management structure and provides the interactive interface with the operator. This program presents a menu of possible processing functions on the console display. When the operator selects one, the program then presents a list of detailed processing parameters for the selected function. The operator may change any or all of the preset parameters, and then he must indicate whether he actually wishes to execute the processing function, or abort. If he chooses to execute the processing, the DINASAR program writes these parameters to a control parameter file, and swaps control to a program to do the processing. The swapped program reads the input parameters, and begins processing, reading and writing data files as needed, and keeping the data file catalog up to date. When a processing function is complete, the swapped program writes to the control parameter file and returns control to DINASAR. DINASAR then asks the operator for the next processing step. This sequence is exactly the same for automatic processing except that DINASAR refers to a preset processing sequence list rather than the operator for the next step, and preset parameters (adjustable in advance) must be used.

3.3.3 Correlation Algorithm

The key component of the DINASAR system is the correlation program which processes radar data to images. The same program is used for both chirp range compression and azimuth compression. Both the received range chirp pulses and the doppler from a target are linear frequency ramps. The processing multiplies that data by a reference frequency ramp with a slope conjugate to that in the data, producing a constant frequency beat signal. The frequency of the beat signal is proportional to the time displacement between the reference ramp and the radar echo signal. This time displacement is the desired quantity for locating the echo in range or azimuth, and is determined by determining the frequency of the beat between the echo and the reference. DINASAR uses a Westinghouse proprietary 2-stage FFT algorithm for determining the beat frequency (imaging). The first stage of the FFT algorithm divides the possible frequency span of the beats in a set of coarse digital filters. The exact beat frequency is determined by performing an FFT on the filter outputs. This algorithm can handle large blocks of input data while performing coherent integration over intervals only as long as the echo signals from a point target, thus conserving processing time.

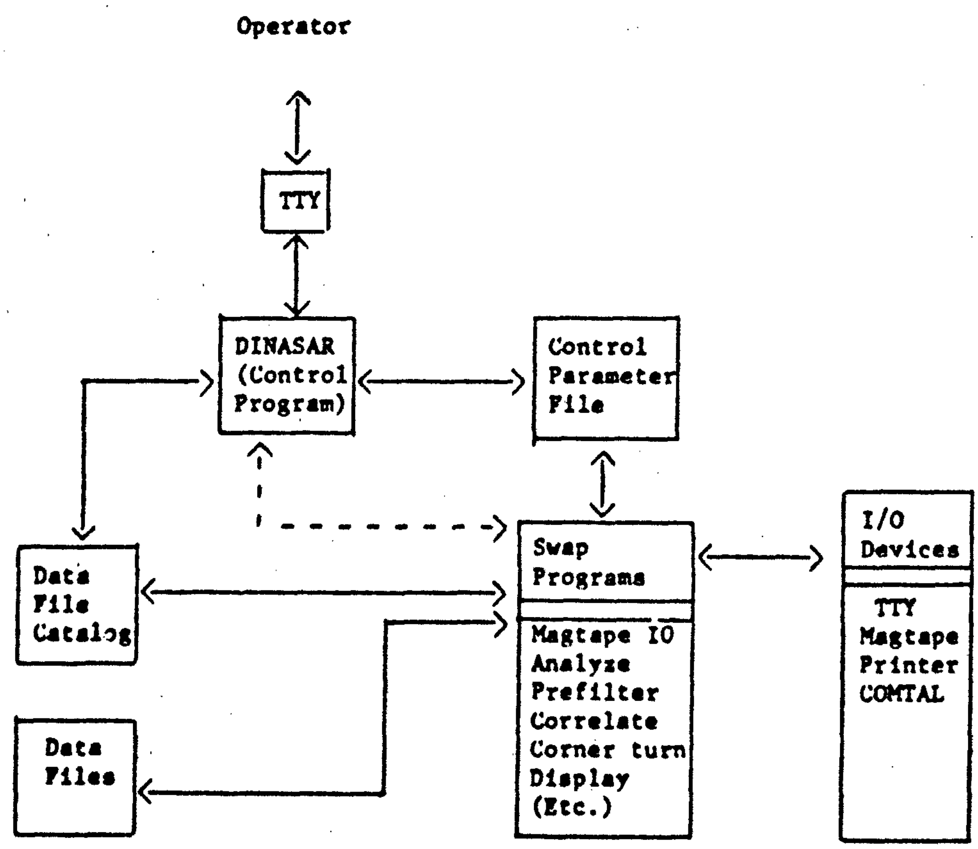

Fig. 11 — DINASAR program organization

3.3.4 Interactive Azimuth Processing

The DINASAR system of programs was developed primarily to assist in solving the problem of imaging moving ships. When a ship experiences accelerated motion (roll, pitch, yaw, heave, surge, sway) its doppler frequency slope changes proportionally to the acceleration. Since DINASAR (and any other SAR correlator) images by matching a reference frequency ramp to the doppler ramp on the echo, different target accelerations require different reference ramp slopes (focusing functions). This focusing function cannot be known a priori because a target ship's motion cannot be predicted in advance.

DINASAR is used for interactive focusing by imaging a ship with the nominal azimuth focusing parameter (determined by the flyby geometry), noting focus errors (quantatively if possible), correcting the focus parameter, reimaging, and so on until a satisfactory image is obtained. This process must be done separately for each portion of the ship with a significantly different acceleration. A mosiac of focused regions of the ship (usually blocks of range cells) is thus assembled for presentation to an interpreter. It is clear that, without a quantative measure of focus error in an image, interactive processing must be very inefficient. It is useful, however, for insight into the process of experimentally determining focus parameters from radar data to allow the development of quantative focus error correction algorithms.

3.3.5 DINASAR Limitations

DINASAR has both fundamental limitations and limitations due to implementation on a Nova mini-computer. The fundamental limitation is that the processor does not correct for range curvature. This limits azimuth resolution to greater than 5 ft for ranges much greater than 30 naut mi.

The facility limitations are due to the size and speed of the Nova and its peripherals.

Core Storage - The longest record which can be correlated is limited to 1650 complex samples.

Disk Storage - The disk pack contains about 48,000 256 word sectors, of which about 6,000 are used for processing and system programs. The remaining sectors must be shared between input data and intermediate results. The longest phase history which has been processed in the fully automatic mode contained 6000-512 complex sample records. If data and intermediate files were deleted after they were used, perhaps 8000 records could be processed. If intermediate results were written over the raw data, perhaps 10,000 records could be processed.

Processing Time - Processing of large arrays literally takes hours. For example, prefiltering an array of 6000, 512 sample records required about five hours. Doing the range correlation required about four and one-half hours. On the other hand, azimuth correlating a small subarray of a scene (such as a complete ship) usually takes between one-quarter and one-half hour. Azimuth correlating a small part of a ship takes proportionately less time.

3.4 Image Manipulations

A number of manipulations pertaining to the geometry and intensity structure of imagery may be accomplished using additional programs for the facility developed for NRL by Raytheon Autometric. This "operating" system, referred to as HIPS (Hybrid Image Processing System), permits a relatively unskilled user to perform an operation on digital SAR imagery like a photo analyst would perform on film. In fact, the software was designed with a skilled analyst in mind as the operator. There are four classes of operations: (1) data handling, (2) manipulations of image geometry, (3) manipulations of image intensities, and (4) display. These operations work with "buffers", which are disk files, typically taking data from the input buffer, performing the commanded manipulation, and storing the output in the output buffer. The buffers are 100 x 100 elements in size; a number choosen so that most operations are done in core and thereby keep up the operating speed. The intensity values are fixed point (integer) variables.

Data handling is a collection of routines that enable the user to read images on tape into the system, store images on tape, or perform like operations with the disk. The prime input is from the NRL Dual Mode scanner that generates digital imagery from an optical correlator output. A listing of the commands is given in Table V.

The geometric manipulations are operations that map the image contained in the input buffer via transformations into an output buffer. A listing of the transformations is given in Table VI. The translate commands are self explanatory. Scale operations involve either an expansion or contraction of the image, depending on the scale factor entered by the operator. Shear is an operation that slides rows in the image a differential amount. Rotations are self explanatory.

The intensity manipulations are also applied to the image contained in the input buffer to generate a new image stored in the output buffer. A command listing is given in Table VII. The histogram operates on the entire 100 x 100 buffer. The clipping operation is standard. The bit plane works as follows. The intensity at a particular (x, y) location can be represented by

$$b(x,y) = \sum_{n=o}^{15} b_n(x,y)2^n \quad \text{where } b_n(x,y) = 0,1$$

Table V - HIPS Data Handling Commands

LR - Load Raw image tape	- reads in a digital image from the tape unit. There are a variety of input formats/data types. Maximum image size is 1024 x 1024. The image is written into a temporary file on the DG disk.
LT - Load 100 x 100 HIPS image from tape	- store a 100 x 100 HIPS working format array into one of the working buffers.
SD - Store on Disk	- store a HIPS 100 x 100 working array in a file on the DG disk. The image is named so as to differentiate it from previous images stored in this file.
LD - Load from Disk	- read a HIPS 100 x 100 working array into one of the buffers. The file and image names specify the particular image of interest.
ST - Store on Tape	- store a HIPS 100 x 100 working array on tape as a file. More permanent storage than disk.
EX - EXtract a sub-array from the full size image	- used with the FS display command which displays a 512 x 512 array; the "extract" pulls out a 100 x 100 sub array (or 200 x 200 averaged down to 100 x 100) to be used as a HIPS working array.
DD - Delete an image	- delete a 100 x 100 image named (.) from file (.)

Table VI - HIPS Geometric Manipulations

SC - SCale uniformly	- "scale" on image; this means magnification or minification by the given scale factor. The algorithm is a simple grid stretching technique followed by simple area weighting.
SX - Scale in X	- "scale" the x dimension of an image; the algorithm is the same as SC
SY - Scale in Y	- "scale" the y-dimension of an image; the algorithm is the same as SC
SH - SHear an image	- "the rows of an image are slid Δx in the x dimension for each Δy increment in the y dimension. The algorithm is zero order interpolation and grid stretching.
RT - RoTate	- the image is rotated an angle θ measured counter clockwise
TX - Translate X	- slide the image in the x dimension - zero order interpolation and fill with zeroes.
TY - Translate Y	- slide the image in the y dimension - zero order interpolation and fill with zeroes.
MR - MiRror	- rotate the image 180° about a y axis that passes through the central portion of the image.
DT - DisTance in pixels	- measure the distance between two points in the image indicated by use of the COMTAL trackball controlled cursor.
GT - Distance in Ground plane	- indicate the distance (entered as in DT) in equivalent ground plane geometry
SS - Slant Range ground range conversion	- convert the distance, entered as in DT, interpreted as slant range, into equivalent ground range.

Table VII - HIPS Display Manipulations

DP - DisPlay an image	- write a 100 x 100 HIPS working array into the COMTAL refresh memory and display this image.
D2 - Display an image	- write a 100 x 100 HIPS working array into the COMTAL refresh memory at double size (200 x 200) by doubling each pixel in both x and y.
DS - Display Side by side	- write two 100 x 100 HIPS working arrays into the COMTAL refresh memory so they are side by side (separated by - pixels) when displayed
OV - OVerlay two image by averaging	- overlay two 100 x 100 images by averaging; write to COMTAL and display
FS - display Full Size	- pick out a 512 x 512 array from a nominally sized 1024 x 1024 image, write the array into the COMTAL refresh memory and display
CL - CoLors	- enter the manipulative routine "COLORS" that operates with the COMTAL psuedo color memory
LE - annotation	- enter the routine "LETRS" which is used to annotate imagery be writing into the COMTAL graphics overlay.
RM - ReMote	- enter the routine "REMOTE" which controls the COMTAL state from the console

Table VIII - HIPS Intensity Manipulations

HS - HiStogram	- form a histogram of the indicated buffer and plot result on hard copy printer/plotter
CI - Clip Intensity	- map all values in the range I_L to I_U (0-63) into the intensity I_R. Simple replacement; I_R is typically zero.
CB - Clip Bit/Bit Plane	- map the input image into an output image that either masks out one bit in intensity or masks to one bit in intensity.
CF - Clip in % intensities	- map the input image into an output image that contains only the (.)% most (least)frequently occuring intensities.
CM - CoMplement image	- take the logical complement of intenstiy - "equivalent" to negative/positive of film.
SI - Scale Intensities	- multiply each intensity by the indicated scale factor
NL - Normalize intensities	- normalize the intensities to (0-63) by the scale factor 63/(max-min)
TF - TransForm the intensities	- map intensities via the specific transfer curve 1-piece wise linear, 2-log, 3-exponential, 4-log exponential, 5-lin log exponential, 6-any eight bits, 7-fold 200 x 200 into 100 x 100

Each of the $\left\{ b_n(x,y) \right\}_{n=o}^{15}$ over the x,y extent of the buffer is a bit plane.

The display routines deal primarily with the COMTAL, but hard copy can be obtained via VERSATEC plots. There are two classes of commands that deal with the COMTAL; the first class writes the image onto the COMTAL, the second enters the manipulative routines that operate the COMTAL. A listing of commands is given in Table VIII.

3.5 Color Display

The digital image display device shown in Fig. 12 is a COMTAL 5317. This device converts a digital image represented by a rectangular array of numbers into an eye stimulus in the form of a television picture (B/W or color), with rows of the array corresponding to lines of the TV raster and amplitude of the numbers corresponding to brightness or color in the TV representation. The COMTAL system stores the displayed image on a magnetic disk, performs scan conversion, and provides refresh for the TV display subsystem. The display subsystem is very flexible and controllable via software in the Nova. The actual physical display is done with CONRAC RHM-25 broadcast TV monitor. The display format can be either B/W or color.

A block diagram of the system with principal components is shown in Fig. 13. The disk memory is configured in this model to store two 512 x 512 element (pixel) images. Each element has eight bits of brightness resolution. There is also a graphics overlay storage of 512 x 512 elements with one bit of brightness resolution. Data are written onto the disk with one disk sector corresponding to a line in a TV raster. Thus, scan conversion is performed upon input. The display of brightness or color is controlled by the function and pseudo-color memories. There are a maximum of 64 gray shades or color that can be displayed at any one time. Control of the gray shade or color equivalent of the element or pixel amplitude is controlled one pixel at a time. The function memory operates first to map the eight bits (or 256 levels) of brightness resolution into a six bit display pixel (64 levels). The map can be anything that can be written into a 256 x 64 look up table. The pseudo-color memory operates on the six bit display pixel to generate gray shades or color. In gray shades, the six-bit display pixel is used equally on the D/A converters that drive the red, green and blue guns of the CONRAC monitor. In color, another mapping is made that takes 64 levels into 64 colors using a 12 bit word for each color — four bits each for green, red, and blue. The trackball controls a small cross that can be positioned anywhere on the screen. Its position can be read or set by the Nova, and with this loop it provides for interaction between user and display.

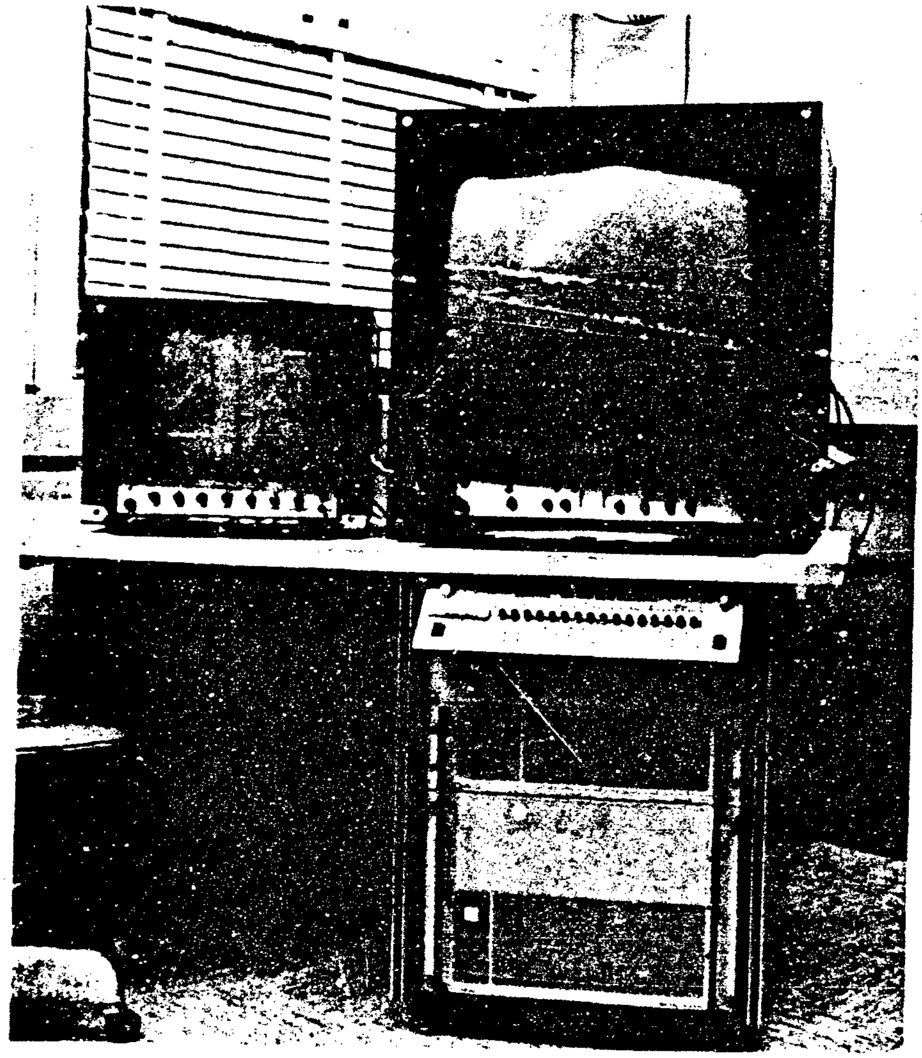

Fig. 12 — COMTAL display

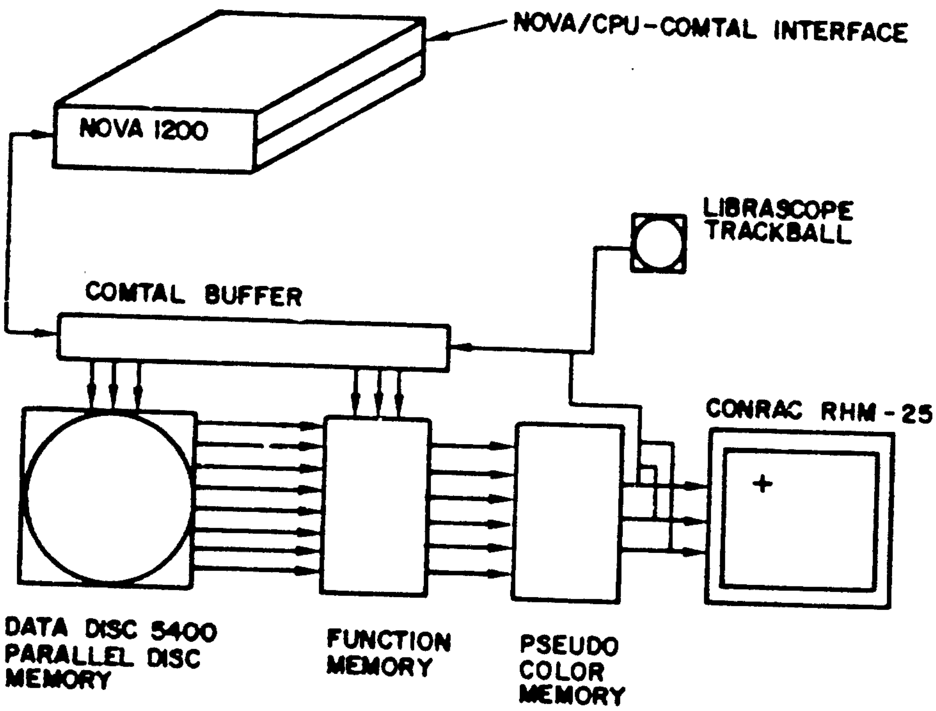

Fig. 13 — COMTAL system diagram

The conversion from the two-dimensional number array in the processor to the displayed image, proceeds in two steps as diagramed in Fig. 14. The first step is a "reformating". Since this step is typically very problem dependent, it is embedded in the processing (DIGISAR/HIPS, etc.) software. The second step, conversion to an eye stimulus, is performed by the COMTAL 5317 Digital Image Display.

Equipment Description

The germane portions of the display facility are diagramed in Fig. 15. The facility is built around the Nova 1200 minicomputer and a large Data General Disk. The operating system is Data General's RDOS (Real Time Disk Operating System). Imagery, represented by an array of numbers, is stored on the disk organized by files, as is the software that operates the Digital Image Display. The operating system enables a user to control system operations from the console. The first conversion block of Fig. 14 resides in the Nova/Disk combination as software that, as its output, communicates directly into the display or into files formated for the display.

The second conversion of Fig. 14 -- number array to eye stimulus -- is the COMTAL 5317 Digital Image Display. This equipment operates as a standard peripherial with the Nova. The major subsections of the COMTAL are shown in Fig. 16; the interface is a standard I/O board housed in the Nova mainframe. The other elements are housed in a separate enclosure shown in Fig. 12. A brief discussion of each element of the COMTAL is in order as it is fundamental to the operation of the display handler.

The storage element of the COMTAL is a Data Disk Model 5400 Parallel Memory Magnetic Disk designed for use with CRT's. As configured in the COMTAL 5317, the disk can hold two image number arrays (each array has 512 x 512 elements -- each element is stored with 8 bit resolution). Also, there is one graphics image of 512 x 512 x 1 bit. The image number arrays are organized by "lines" as shown in Fig. 17. The lines are the lines of the television raster and are equivalent to the rows of the image number array*. The basic entry into image storage is thus one line = 512 eight bit bytes or 256 Nova words. Entry is made through the COMTAL controller which contains a buffer that unloads the Nova memory in a DMA (Direct Memory Access) transfer. When 512 elements have been passed or completion of a short line transfer is signaled, the buffer then waits until the designated line

* Actually, there is room on the disk to store approximately 37 more lines in each image; however, these lines are lost to the viewer in the vertical retrace time of the television monitor.

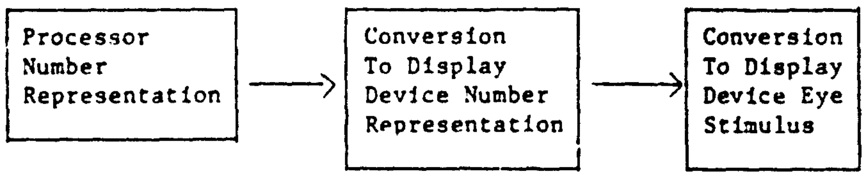

Fig. 14 — Digital SAR processing facility image formation

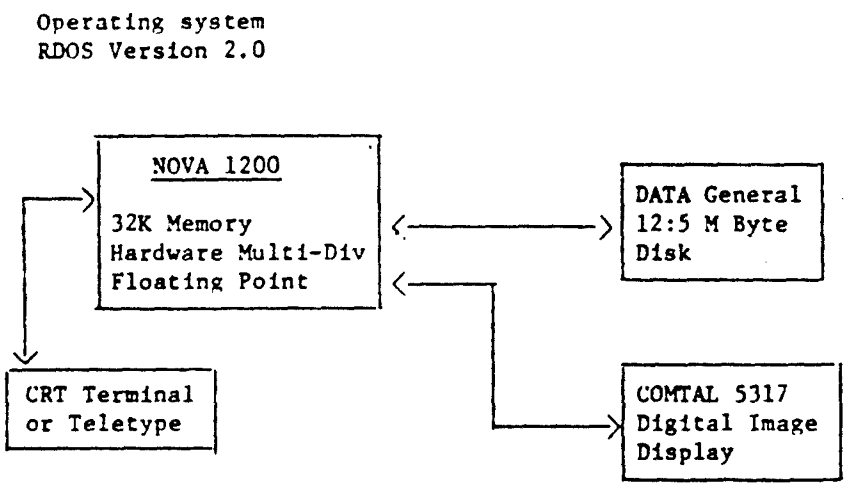

Fig. 15 — Display function equipment

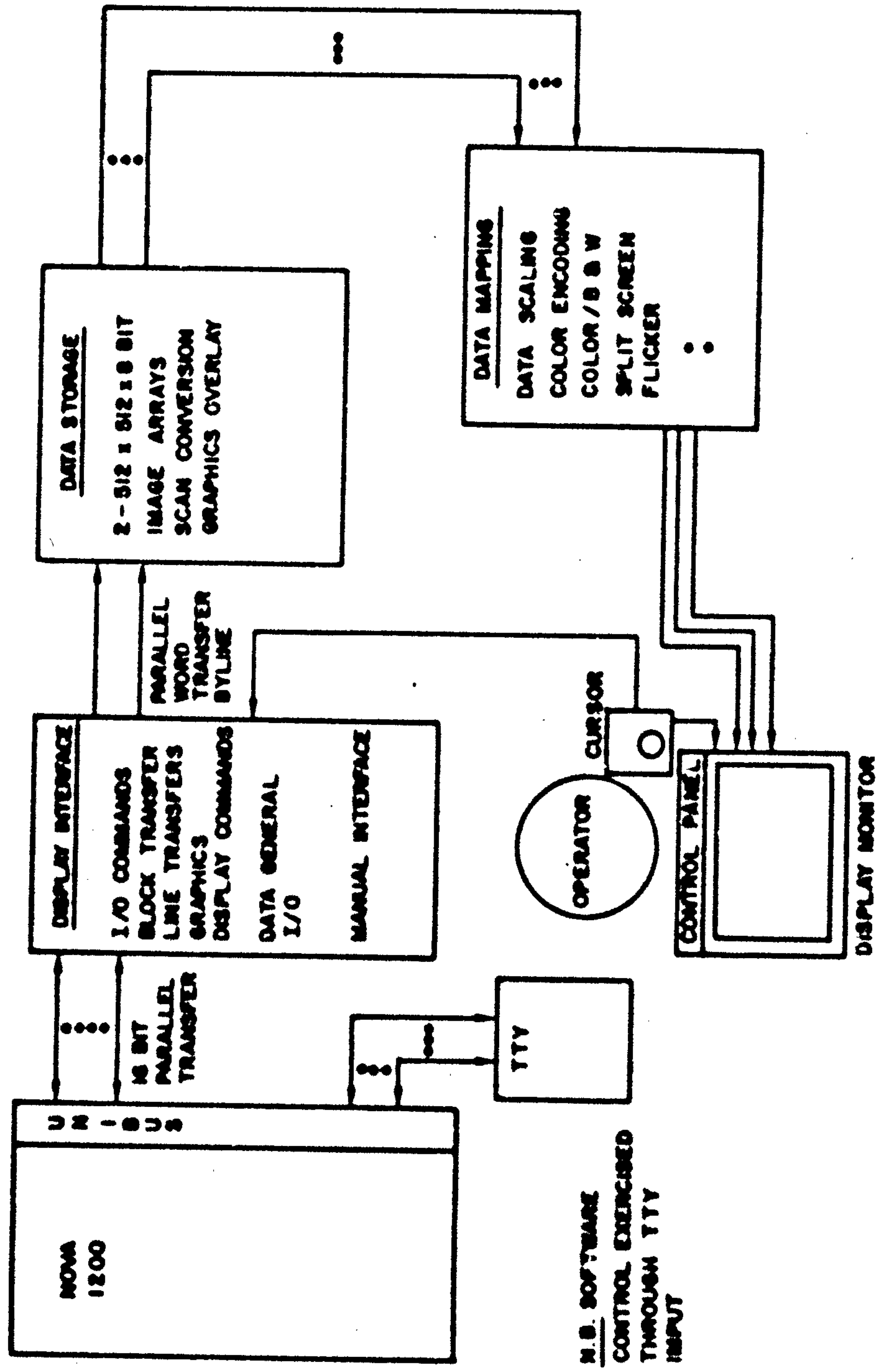

Fig. 16 — Display system functional block diagram

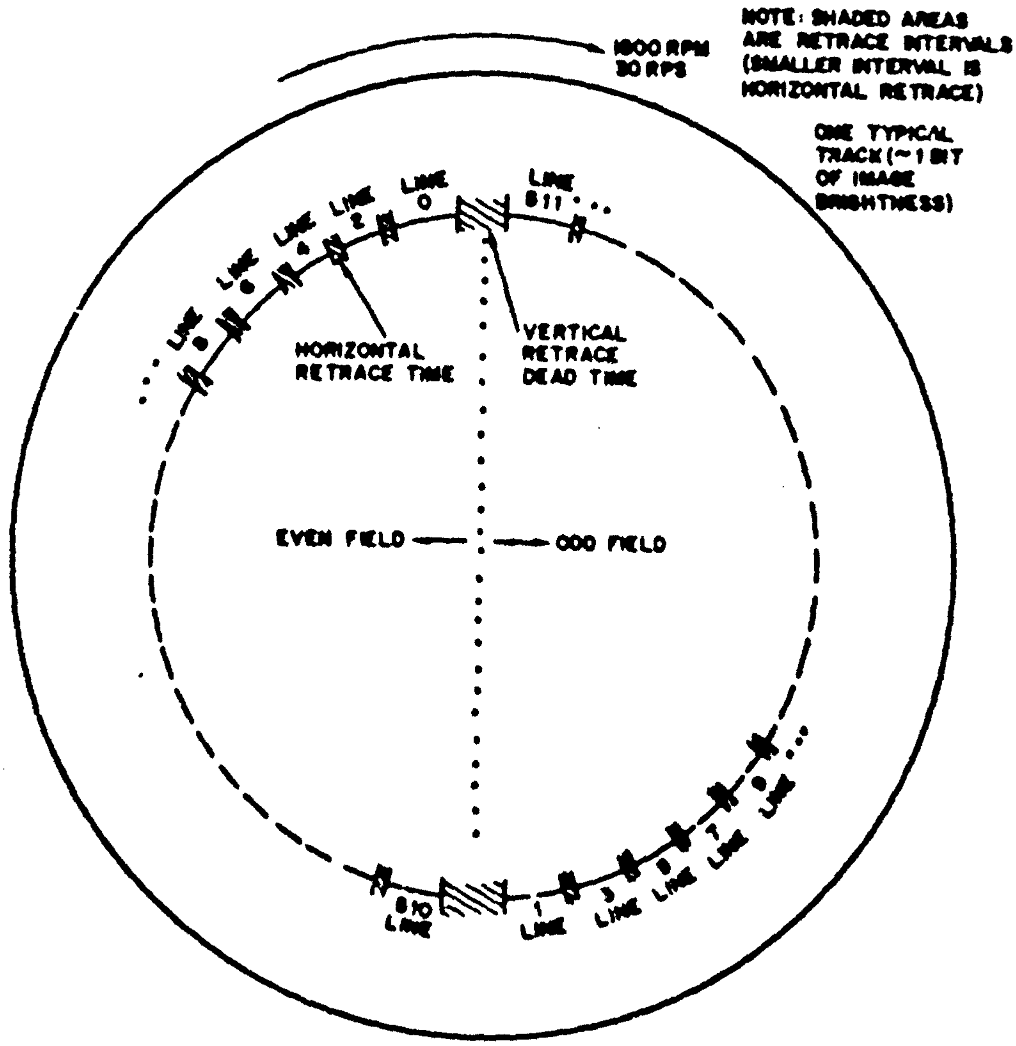

Fig. 17 – Disk storage layout enabling scan conversion to TV raster when read out

is under the write head of the disk and then writes the full 512 element buffer into that line segment on the disk. Thus, the number array is written out a row at a time so that when read back, the rows become the lines of a TV raster.

The Image Generator operates on each element or pixel in serial fashion. That is, as the storage disk circulates, each line in turn comes under the read head. In each line 512 "points" or pixels are read out (in succession) in step with the scan of the television spot*. As each element is read, the 8-bit value is converted into a signal that controls the intensity of the television spot in that region. This gives a window roughly 50 nsec wide in which to complete the conversion from 8 bit number to screen voltage. The conversion proceeds through a function and color memory. These memories are implemented by random access look-up tables. The first conversion is the mapping of the 8-bit storage pixel into a 6-bit display pixel representation. The default map is to take the most significant six bits, but any transformation that can be written into a 256 x 64 table is possible. The entries of the function memory are loaded from the Nova. The pseudo-color memory is bypassed in gray scale -- the six-bit representation of each pixel is applies equally to each D/A converter that controls the red, green, and blue guns of the CONRAC monitor. In the psuedo color mode, the mapping from six-bit display pixel representation into a 12-bit color word is implemented in a 64 x 12 random access memory. Each 12-bit color word is made up of three four-bit words that are applied to the D/A converters. The conversion train is diagramed in Fig. 18.

The display monitor is a CONRAC RHM-25, a 25" broadcast quality monitor with a shadow mask tube. The scan is operated so as to obtain a 1 x 1 aspect ratio which means that only about 80% of the screen is used. There are 512 viewable lines in the raster generated by the COMTAL. The colors obtained with the CONRAC have been computed with white assumed to be CIE Source C and plotted in Fig. 19. Actually the spread of colors is greatest at low intensities; the brightest colors tend to clump about yellow-green.

Display Operation

The COMTAL is not a manual device; it is designed to be operated as a computer peripheral. The software that has evolved to operate this display is too varied and problem oriented for it to be profitable to describe it in general. However, the software can be simply divided into driver routines and user routines. The driver routines communicate betwcen the Nova and the COMTAL to perform one of the four basic operations:

* In fact the TV synchronizing pulse is generated from a track on the disk.

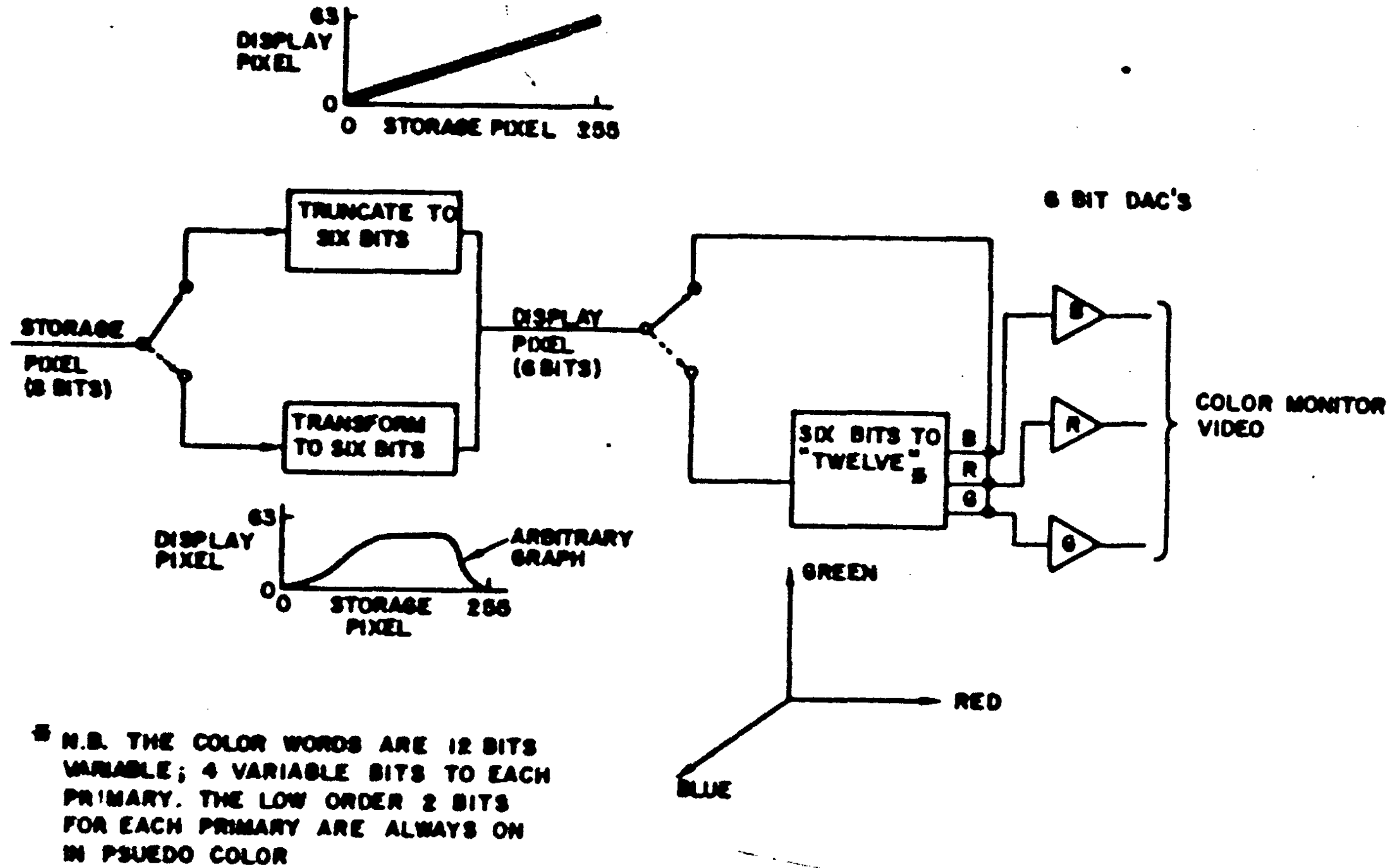

Fig. 18 — Conversion from digital refresh memory pixel to analog voltages to drive TV color guns

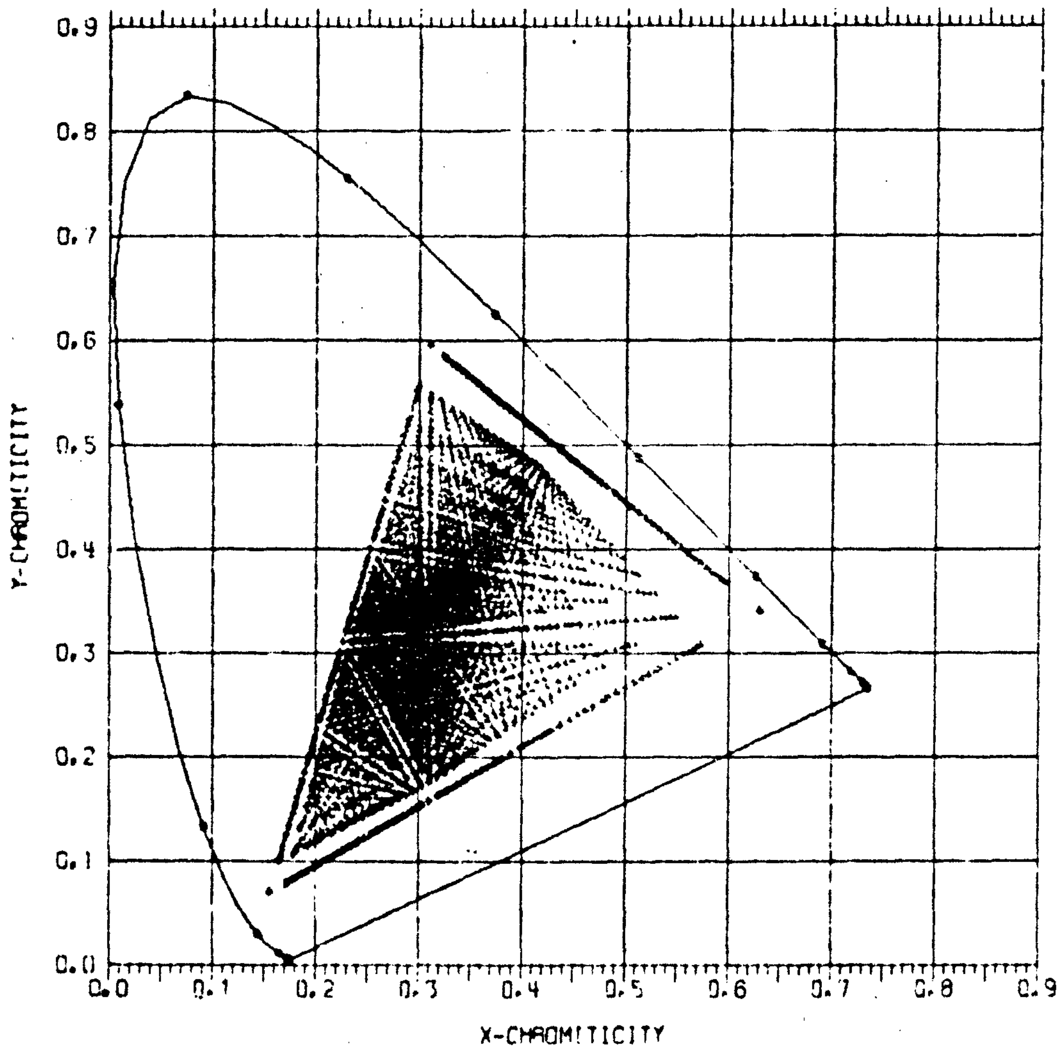

Fig. 19 — Locus of colors available with COMTAL

(1) command the display state
(2) write a line to the refresh memory
(3) wirte to the processing memory
(4) read or position the trackball controlled cursor

User routines are problem dependent. For instance, one routine using (4) allows the user to manually positon the cursor with the trackball when positioned over an element of interest, a key is hit on the console. The (x, y) location of the target is then printed out on the console screen in response. User routines have been written that perform operations of display mode control, writing an image, manipulating the processing memories, and trackball reading and writing. Rather than survey these various routines, two specific programs that use the processing memories will be described in some detail. Both routines are aimed at display of the image so that its "information" is perceptible.

Color Manipulations

The description of this program will be hampered by the inability to reproduce the color effects generated by the COMTAL system. The pseudo-color mode of the COMTAL encodes the shade of gray representation of pixel amplitude into an arbitrary color. Control of this encoding is available through the psuedo-color memory where the encoding is performed. The shade of gray is represented by a six bit word (0-63) that is used as the address of a look-up table. The entry at that address is a 12-bit word that is used (4 bits to each primary) to control the three primaries of the CONRAC color monitor. The entries in the look-up table can be written from the Nova. Color manipulations use this basic hardware and the trackball to provide interaction.

The program is controlled from the console. There are roughly 10 basic color wheels to pick from. A simple mnemonic entered by the user picks out the wheel of interest and loads this wheel in the pseudo-color memory. The most popular wheel, thus far, has been one that steps from black to full red, steps in green to make yellow, steps in blue to white, and removes green to purple. This scheme mimics the spectral colors. At this point there are a number of options:

(1) Trackball control - the color wheel is arbitrary in that it generally does not have an obvious start and finish. To take advantage of this ambiguity, the color wheel is repeatively loaded into the pseudo color memory starting at a location controlled by the x location of the trackball. This is analogous to wrapping the color scale, which is printed on a piece of paper, about a cylinder which has scribes that are numbered 0 - 63. The wrapping can start anywhere on the cylinder. By putting the starting location under control of the trackball, the

user can obtain an almost tactile sense of how the intensities of the image are distributed.

(2) Automatic stepping - here the starting address is put under clock control that rolls the color wheel at a selectable rate up to 30 steps/sec.

(3) Invert the scale.

(4) Reduce the number of color steps. Too many color steps, which are generally more preceptible than the equivalent steps in gray, can lead to breakup the image. One way to combat this is to use fewer steps.

(5) Pick another color wheel. These operations occur in real time so that the user is not aware of the mechanics.

There are two other color manipulations that are similar in nature. The first involves using a bright green band controlled by the trackball to roll through the intensity range of an image (this can be done with either a gray scale or pseudo-color presentation). All elements whode intensities are the same as the intensity derived from the x-location of the trackball are colored green. The effect to a user, is to be able to roll the green band back and forth through the intensity range of the image. This technique easily pinpoints the birght elements. The other mode is slice the image with three colors. A band of red is controlled by the trackball; all elements whose intensities are the same as the intensity derived from the x-location of the trackball are colored red. All intensities below are represented by blue; all above are represented by green. This three color system can give a sense of the image structure.

The simple controls sketched above are intended to aid a user in ferreting out a cuitable presentation of an image. Based on a relatively small sample of imagery, the use of color seems to be a powerful tool in making information content of imagery visible. However, it is not clear *a priori* how this can best be done.

Scale Manipulations

The next routine described uses the function memory of the COMTAL to control how the eight-bit storage pixel is converted into six bits for gray shade or pseudo-color display. Control is effected in the same manner that pseudo color is controlled; the function memory is a look-up table with the amplitude of a pixel used as the address. The entry at that address is a six-bit word that is written into the table from the Nova; the trackball is used to provide interactive control.

There are nine scale types:

(1) The linear scale shown in Fig. 20a. Here the domain of the scale is controllable and the amplitudes above saturation may be left full on or set to zero. By controlling the starting point of the scale with the trackball, a linear scale can be applied to any segment of the eight bit range of the image amplitude. It is not too uncommon to find interesting detail in land scenes in the first few levels and the strong targets clumped at the highest levels. Using this simple linear scale on such an image quickly reveals this intensity distribution.

(2) Linear scale with variable saturation as shown in Fig. 20b.

(3) Two slope linear scale as shown in Fig. 20c.

(4) Logarithic scale as shown in Fig. 21. The shape of the logarithmic scale is controlled by two parameters which control the saturating amplitude and the slope of the logarithmic curve.

(5) Intensity slicing as shown in Fig. 22. This scale is similar to color slicing in that a three-intensity system is used. A band of amplitudes whose amplitude matches the amplitude derived from x-location of the trackball is set to a mid-range intensity. All amplitudes below are set to a lower intensity; all amplitudes above are set to a higher intensity.

(6) Bit select as shown in Fig. 23. The amplitude of any pixel can be represented by the sum

$$b(x,y) = \sum_{n=0}^{7} b_n(x,y)\,2^n$$

where

$$\left\{b_n\ (x,y)\right\}^7_{\ n=0} = 0,\ 1$$

Bit select enables the user to pick out any contiguous block of up to six bits.

(7) Bit planes enables the display of the individual $\left\{b_n(x,y)\right\}^7_{\ n=0}$ to enable a quick check on the noisiness of any particular bit.

(8) Amplitude clip zeroes out some range in the scale.

In addition to the various scales described above, there is an option to manipulate the scale with the trackball. By setting the

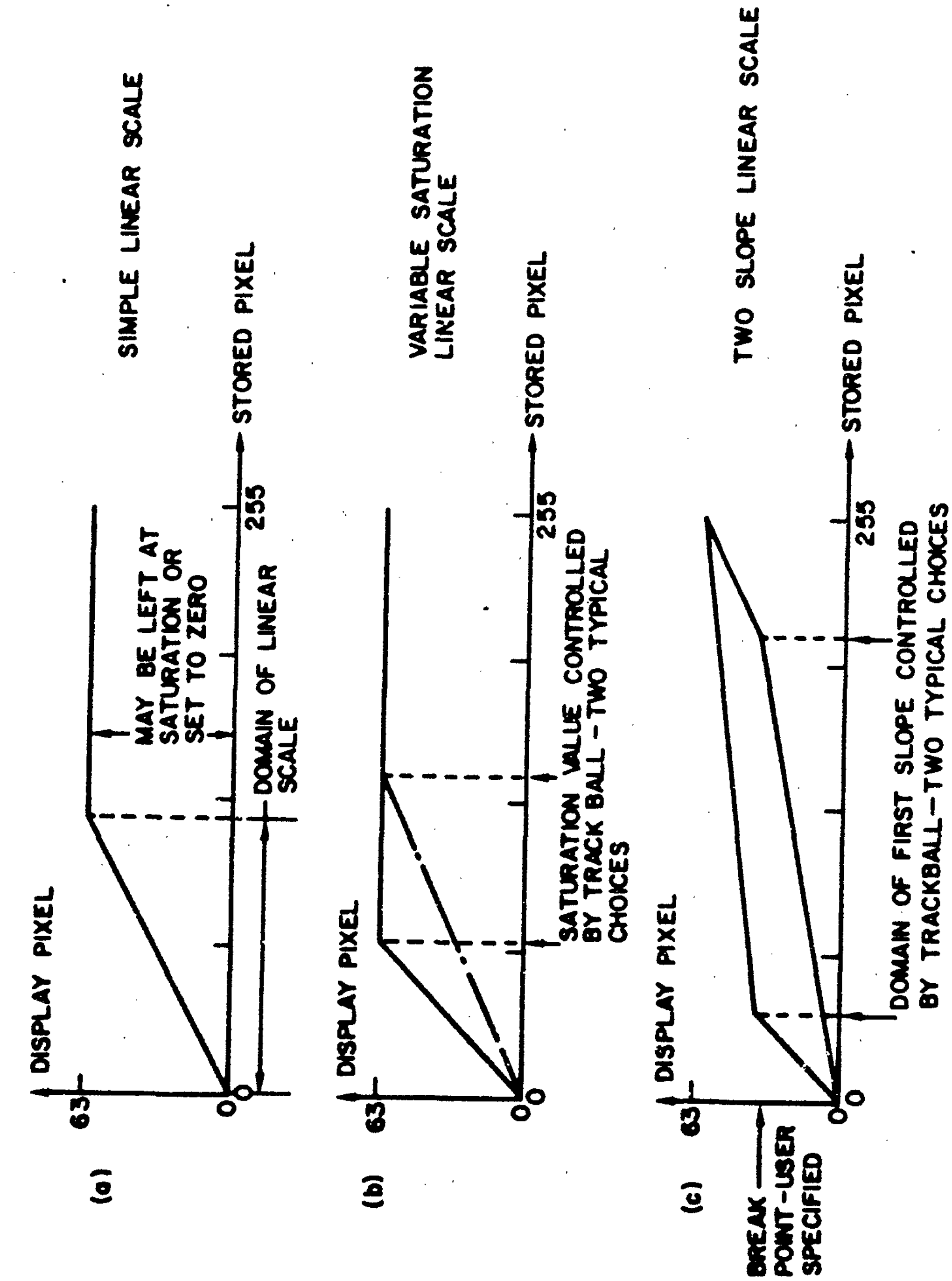

Fig. 20 — Linear scales

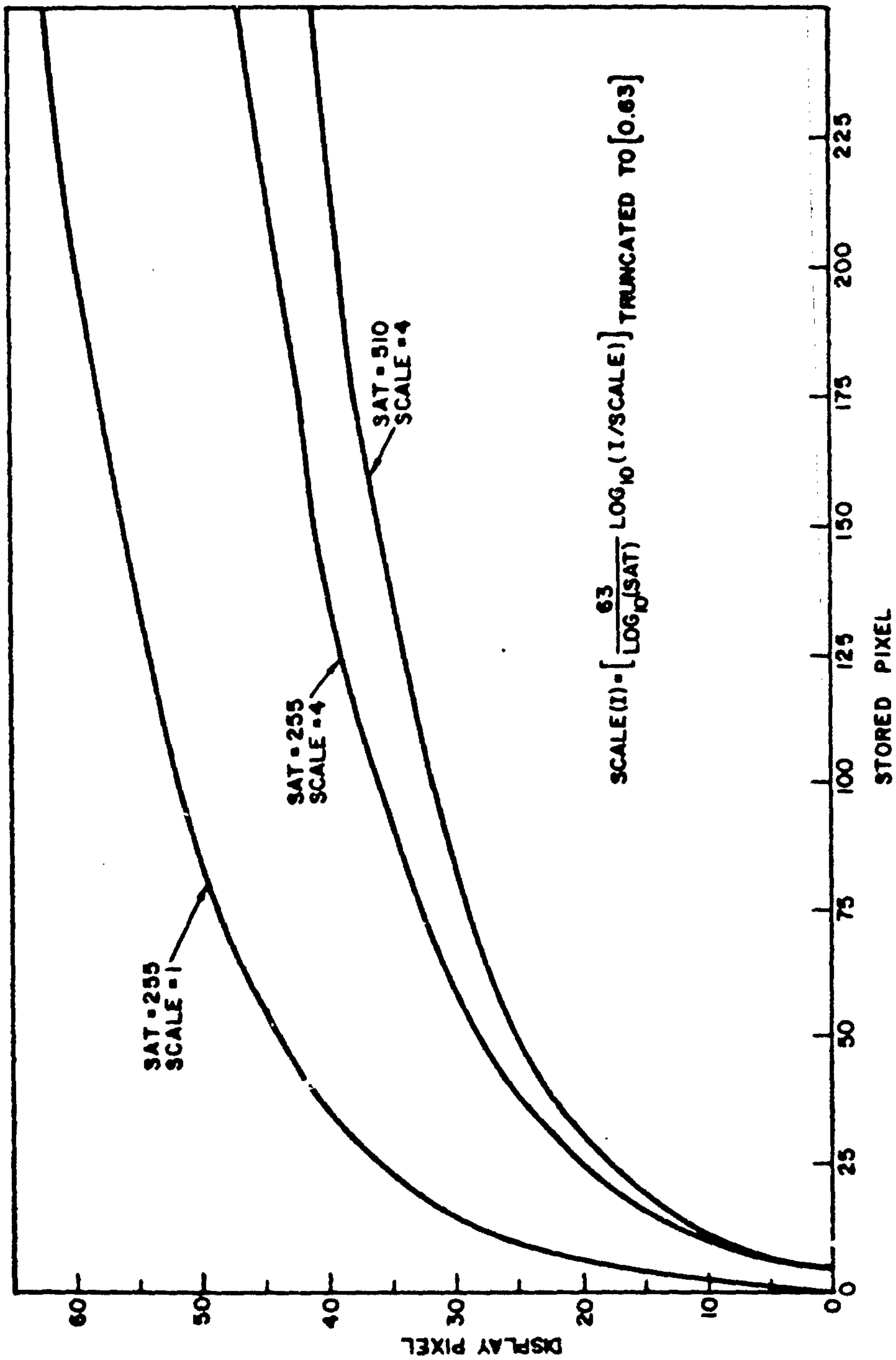

Fig. 21 — "Log" scale

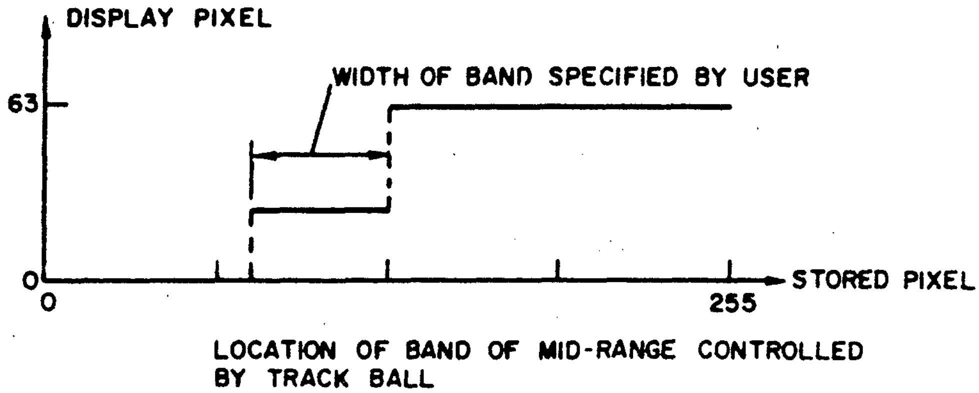

Fig. 22 — Intensity slicing

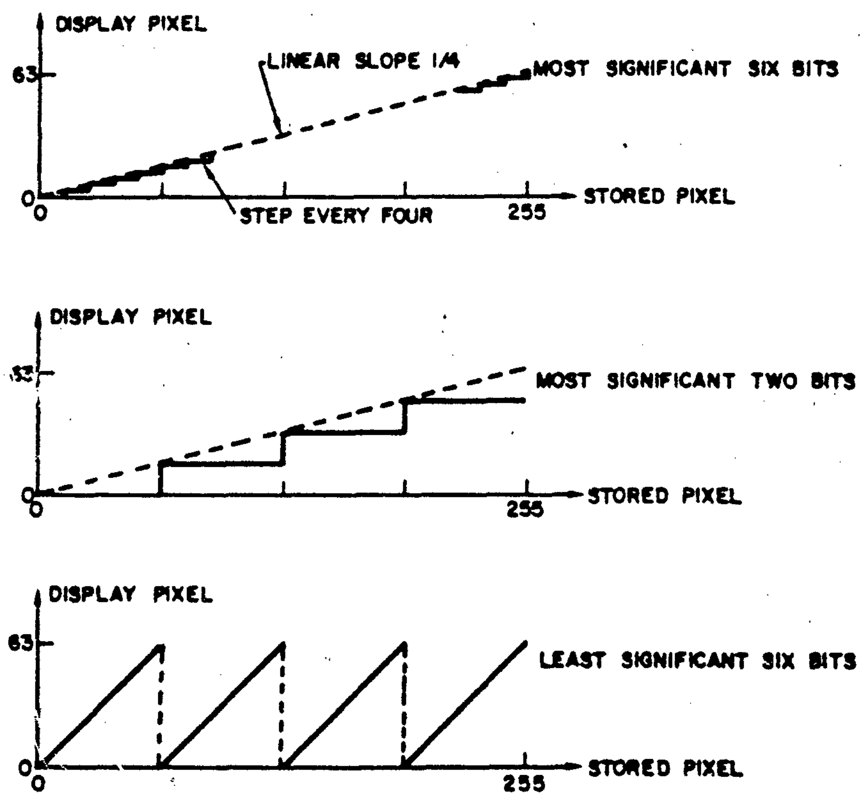

Fig. 23 — Bit select transfer curves

starting location of the scale in the function memory to the amplitude derived from the x-location of the trackball (the smaller amplitudes are represented by 0 brightness), the scale can be rolled through the amplitude range of the image. This rolling can also be controlled by a clock. Inverting the scale is another option.

Again the intent of this routine is to provide the user with tools to increase the information content of the displayed image. Based on the small sample of imagery generated up to this point, the scale manipulations appear to be a powerful tool towards this end.

4. Typical Output Resulting from Facility Operations

This section will demonstrate the acceptable performance of the components of the SAR interpretation facility by showing output produced through use of each component. The principal output of the facility is imagery displayed on the color TV monitor. It is the result of operations in the various data-flow paths shown in Fig. 1.

The data paths have common elements, so a useful image jointly confirms more than one component. All displayed output uses the tape handler, computer, display software, and display hardware; thus, all the images demonstrate the correct operation of these system elements. Digital phase histories require correlation to produce images, so all the images from digital histories demonstrate the operation of the DINASAR correlation programs as well as the digital phase history sources.

4.1 Digital Phase Histories and Correlations

4.1.1 Perkin-Elmer Scans of Film Phase Histories

Perkin-Elmer scanned and digitized 12 phase histories from Project RICE data. One of these was the first real phase history correlated by the DINASAR program at NRL. Figure 24 shows the phase history displayed after the prefilter operation. The range direction is horizontal and the azimuth is vertical. Note the hyperbolic zone plates in the image. Figure 25 shows the data after correlation in range only. Range is the vertical dimension. The horizontal streaks are scatterers which give returns for many pulses. The intensity modulations are cuased by interference among multiple targets within the same range cell. Figure 26 is the complete correlation of the data. It is immediately recognizable to a trained interpreter as the radar image of a cruser. The blob to the left of the ship is a doppler ambiguity, or poorly focused energy caused by incorrect positioning of the doppler spectrum within the frame of PRF lines. This is an error in the data rather than an error in the correlation program.

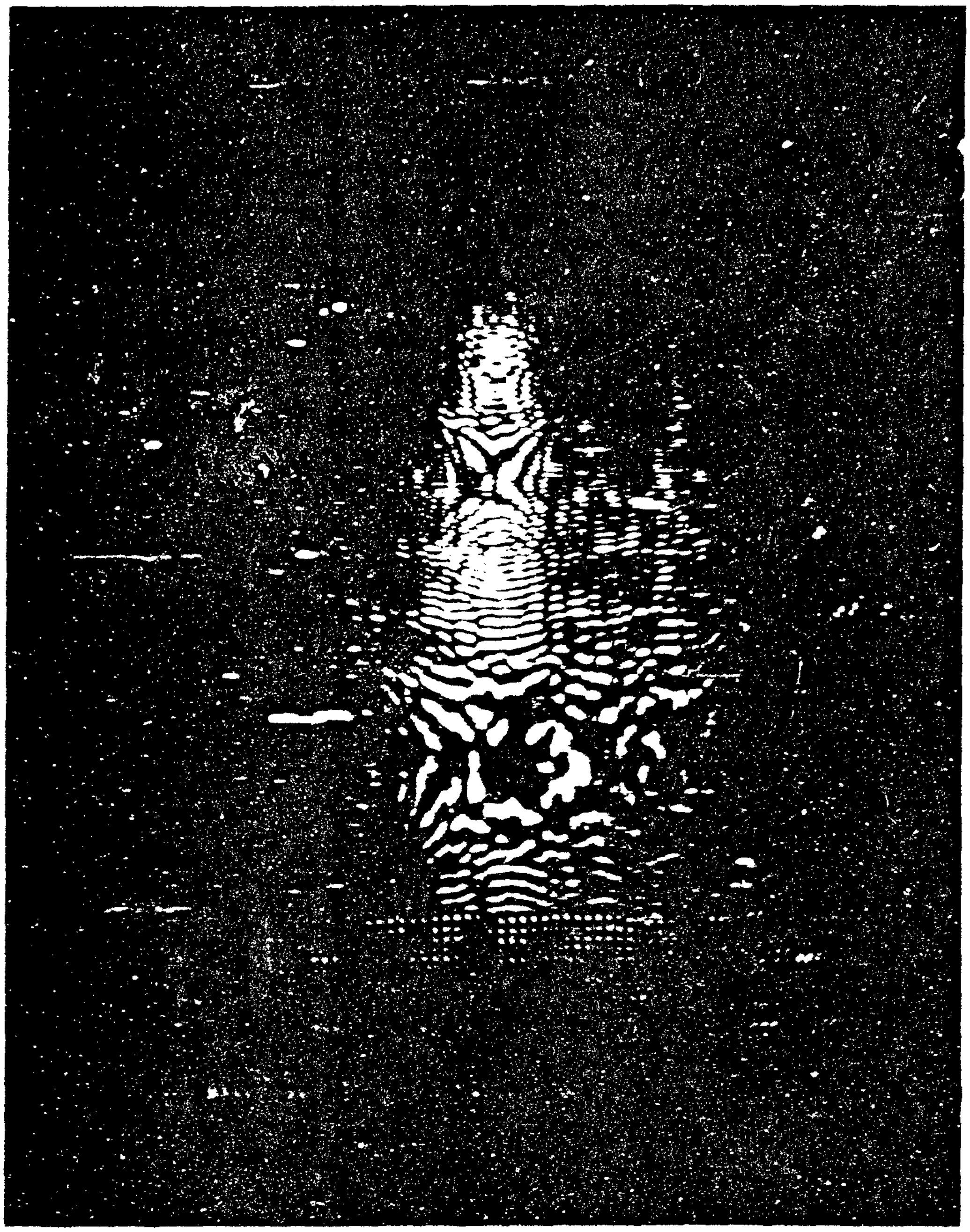

Fig. 24 — Prefiltered phase history of ship

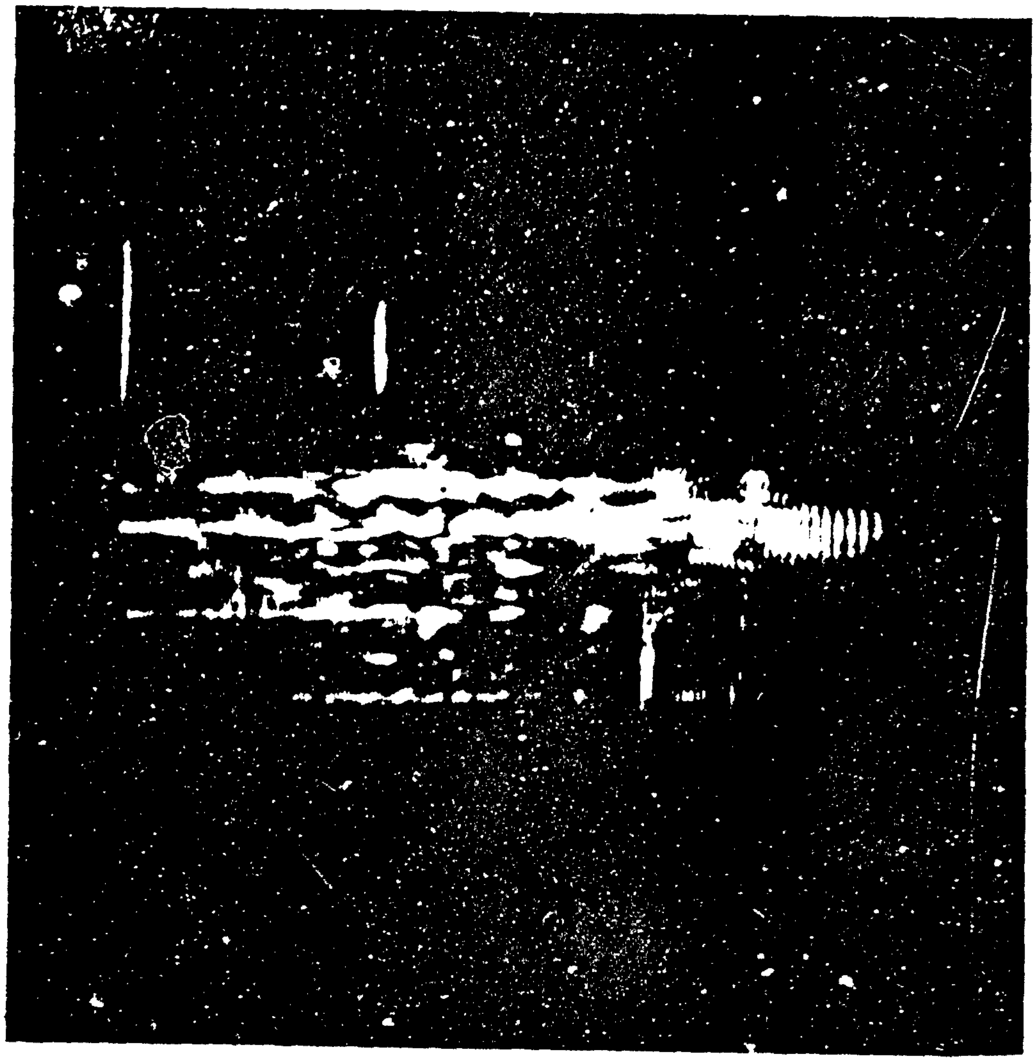

Fig. 25 — Range compressed ship

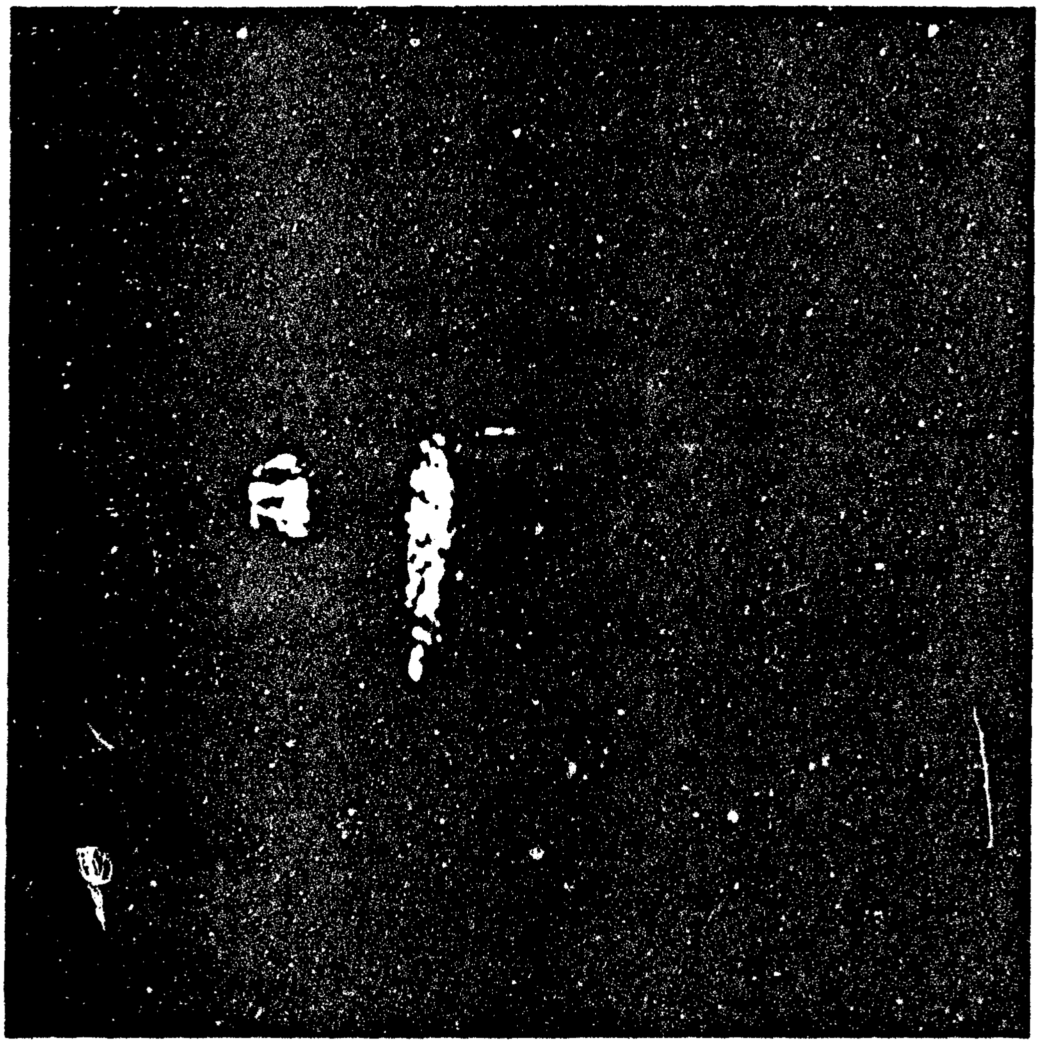

Fig. 26 — Digitally correlated ship

4.1.2 Air-Force Phase Histories

The Air Force produced several phase histories directly digitized from raw radar data. Figure 27 shows an image correlated at NRL from one of these tapes -- the scene is the settling pond area at 29-Palms, California. This scene has about 10' resolution and its size is about 2000' x 2000'. This scene was quite an acceptable image on the color TV display; photographed in black and white, it is very poor.

Figure 28 is a digital correlation of another Air Force phase history. This scene is a static corner reflector array at Luke AFB near Phoenix, Arizona. Figure 29 is a photograph of exactly the same image data, logarithmically converted. The scene is near an air-strip. The ground truth sketch for the scene is shown in Fig. 30. These images demonstrate the problem of dynamic range and the need for a color display. The scene has in excess of 40 dB of dynamic range, but it is very difficult to display and reproduce a scene in black and white so that both dynamic range and resolution are preserved.

4.1.3 Phase Histories from Dual Mode Scanner

The film phase history of a harbor scene was scanned and digitized with the Dual Mode Scanner. The correlated result, two freighters tied up at a T-head pier, is shown in Fig. 31.

Figure 32 A-C are three digital correlations of the same ship at sea whose film phase history was also scanned by the Dual Mode Scanner. These figures indicate the interactive potential of the digital correlation program. Figure 32a is the nominal focus determined by the fly-by geometry. Figure 32b was refined by repeatitively recorrelating the stern region of the ship to focus for the left-rear targets. The right rear targets were focused in Fig. 32c. This is an example of the interactive experiments which can be performed to gain insight into the problem of producing classification quality imagery of ships at sea.

4.1.4 Phase Histories from the NRL Airborne Recorder

The airborne recorder was flown over Vandenburg AFB. The in-phase component of a portion of the phase history is shown in Fig. 33. The horizontal direction represents 400 range elements, and the vertical is 512 pulses. Hyperbolic zone plates from strong scatterers are clearly visible. Figure 34 shows the same scene compressed in range. The vertical dimension represents about 1500 ft in ground range. Horizontal streaks are caused by strong targets. The fully compressed scene is shown in Fig. 35. The azimuth width is about 3600 ft. This scene suffers from reproduction of a small area, large dynamic range scene with black and white photography. It does, however, show that

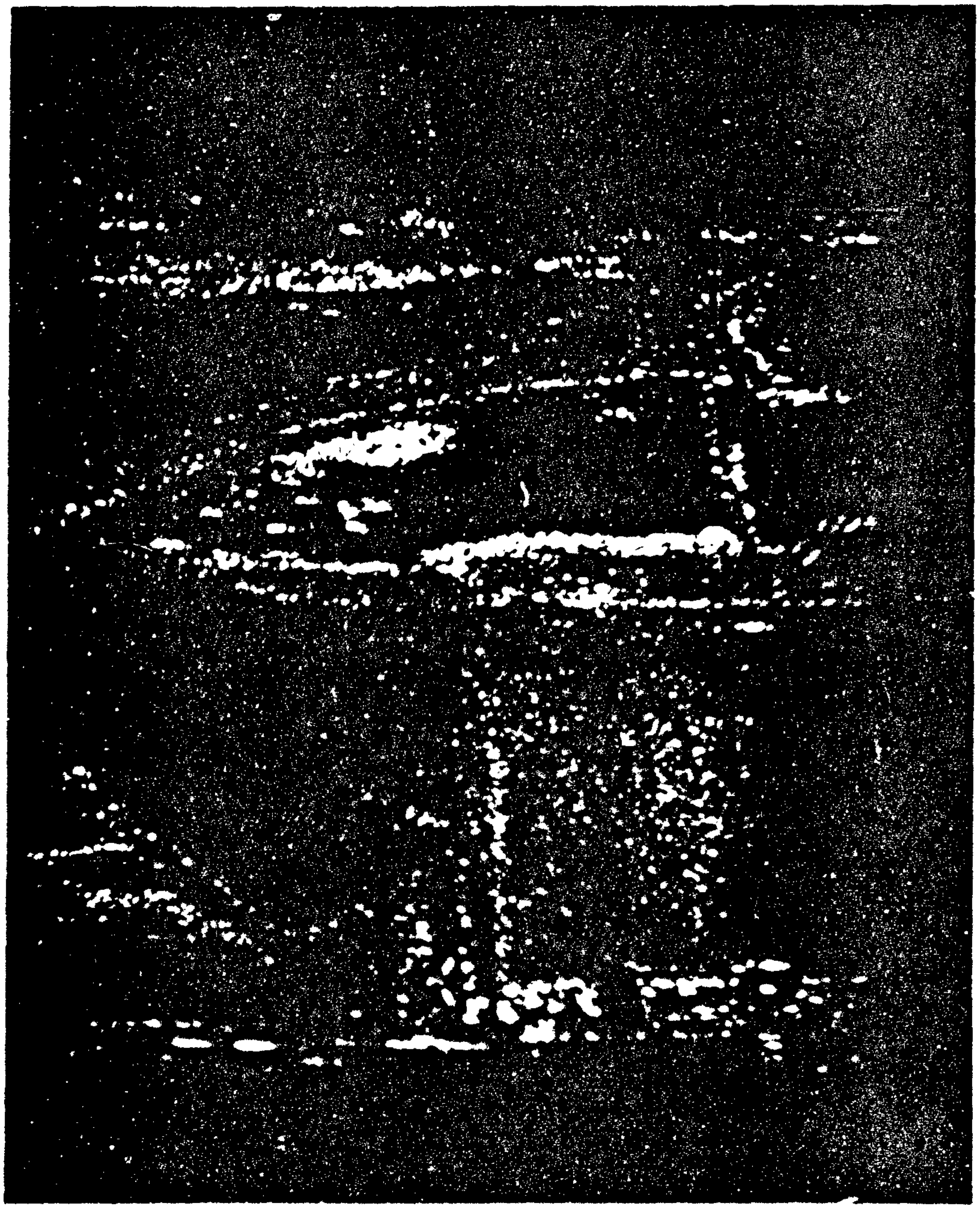

Fig. 27 — Digitally correlated 29-Palms scene

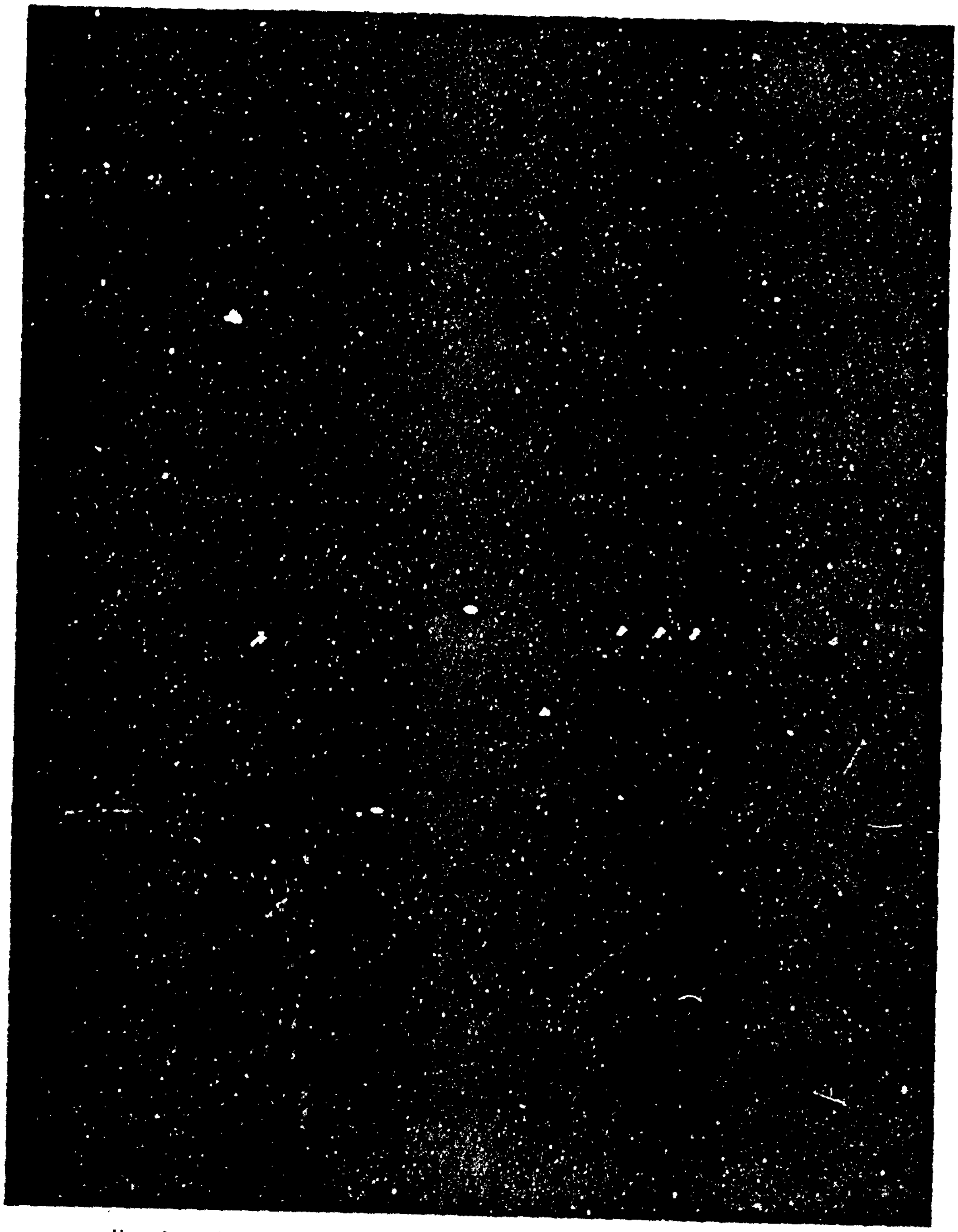

Fig. 28 Digitally correlated Lake test array linear amplitude display

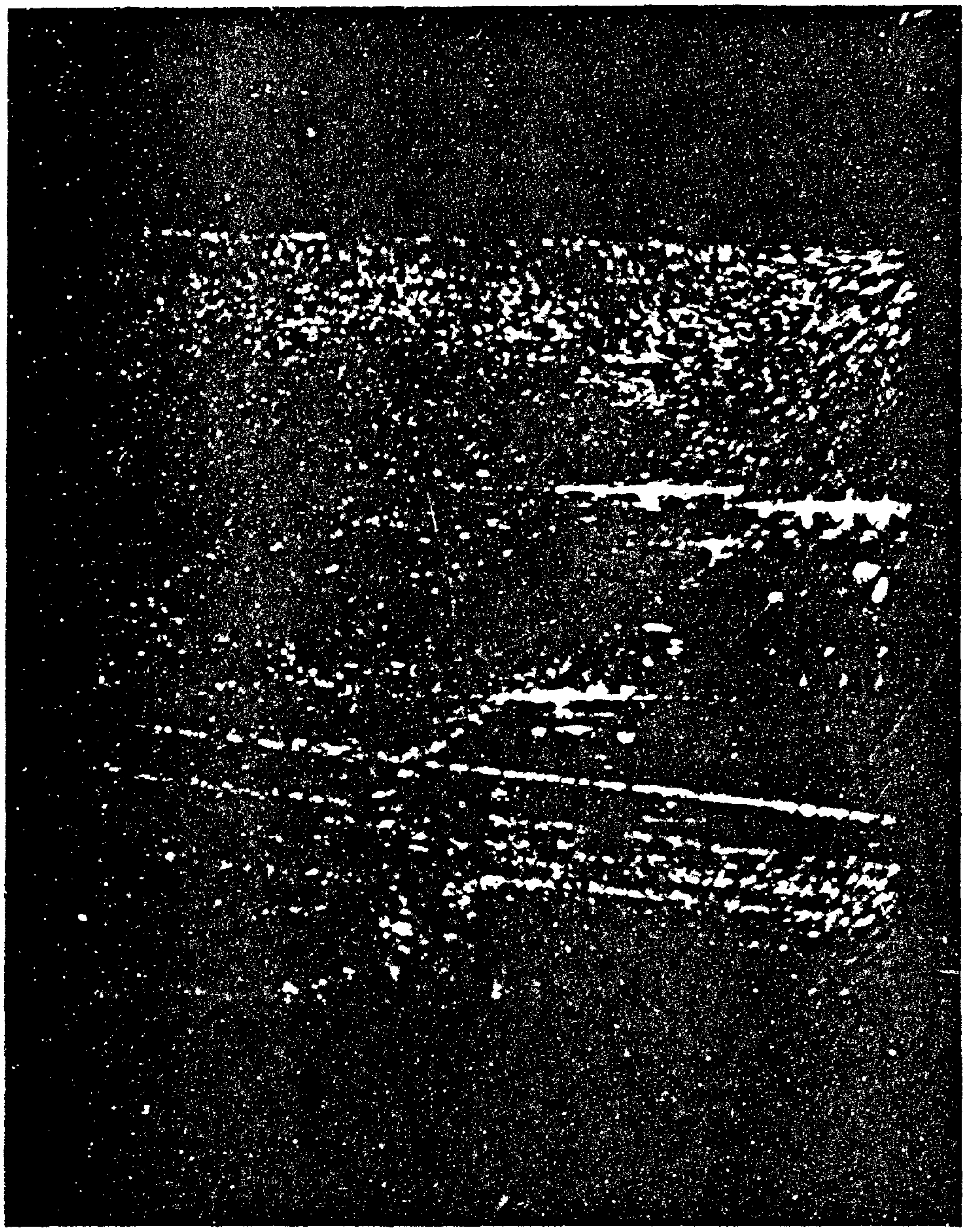

Fig. 29 Digitally correlated Lake test array-log amplitude display

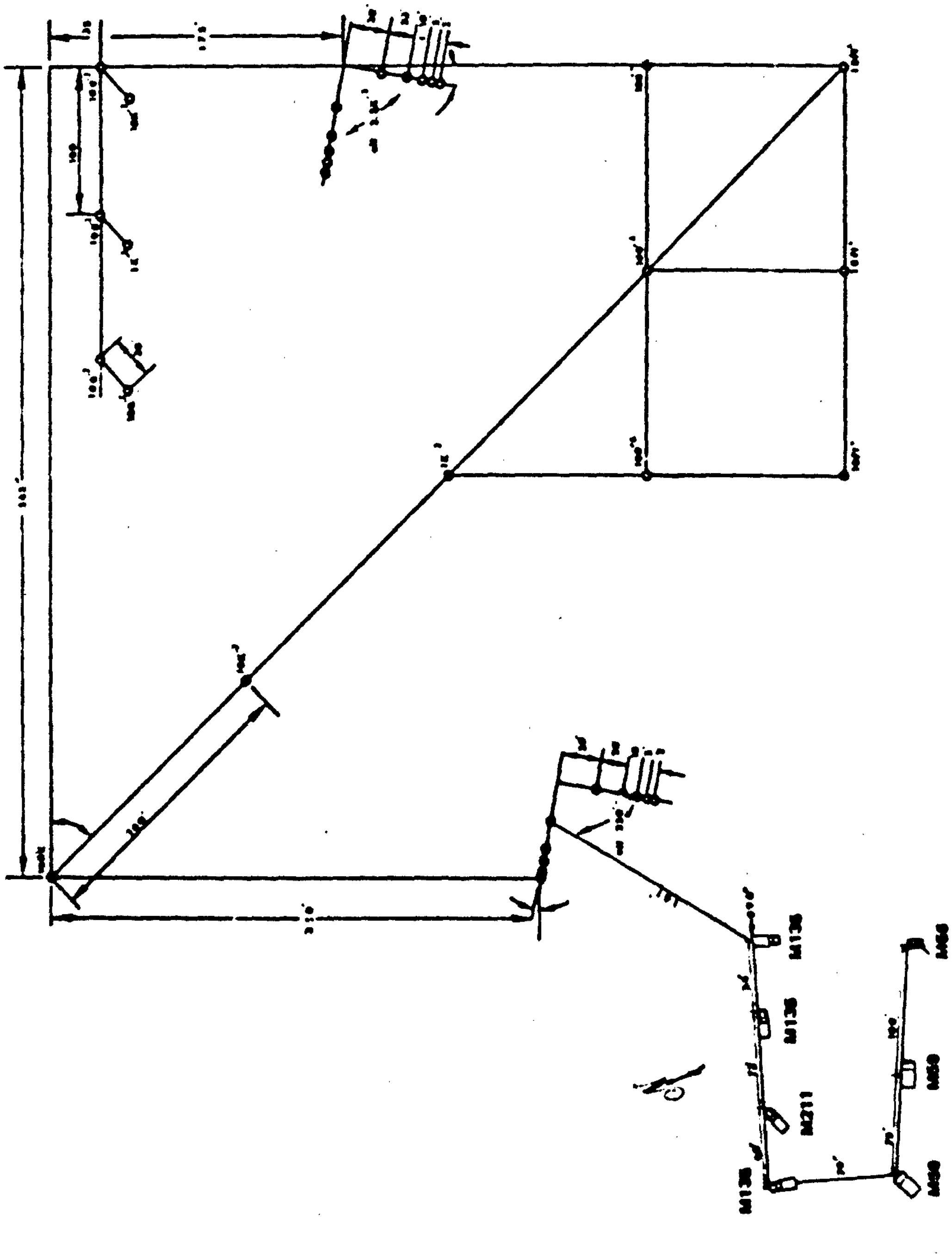

Fig. 30 — Luke test array ground truth

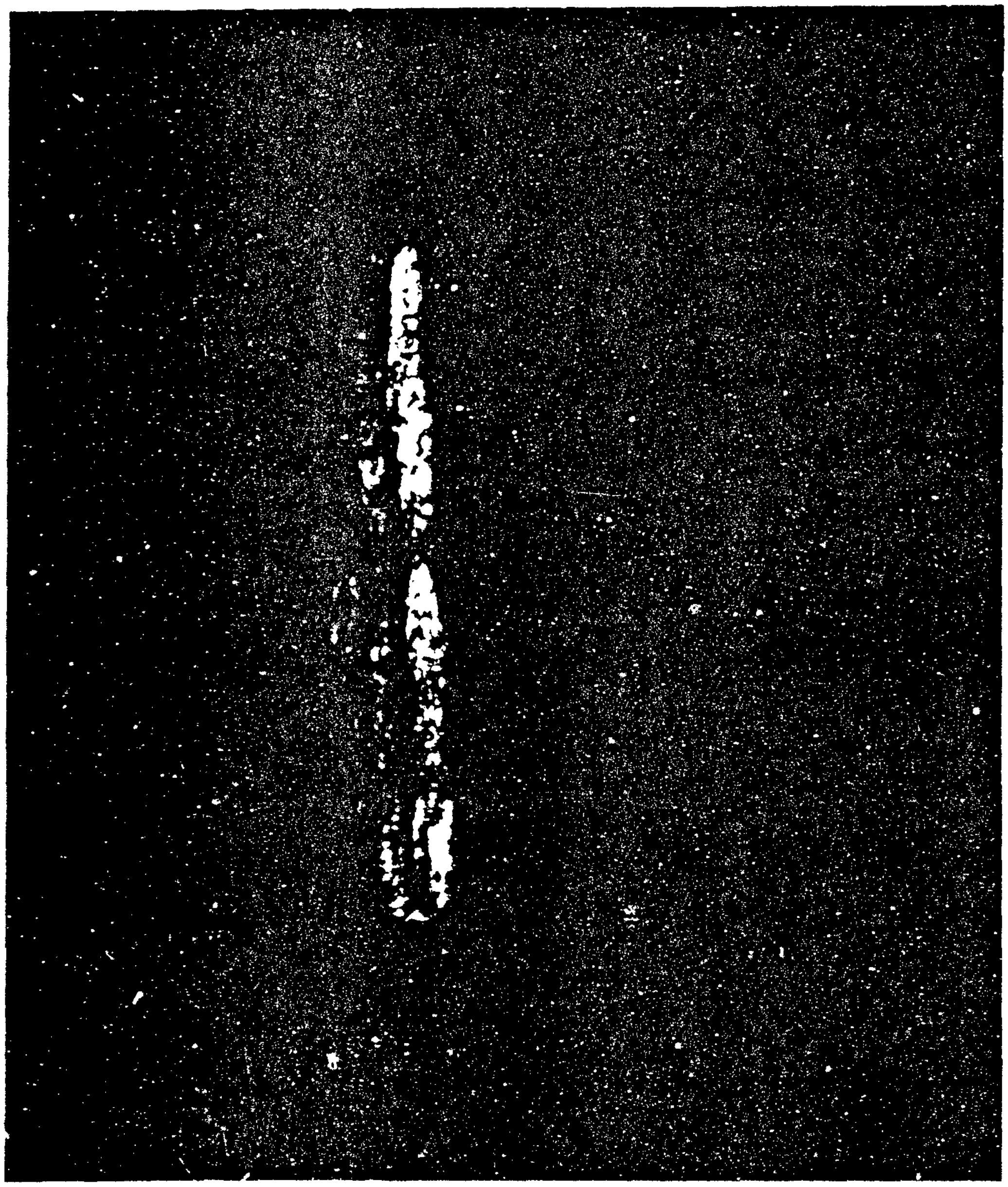

Fig. 31 — SAR image of two ships at pier

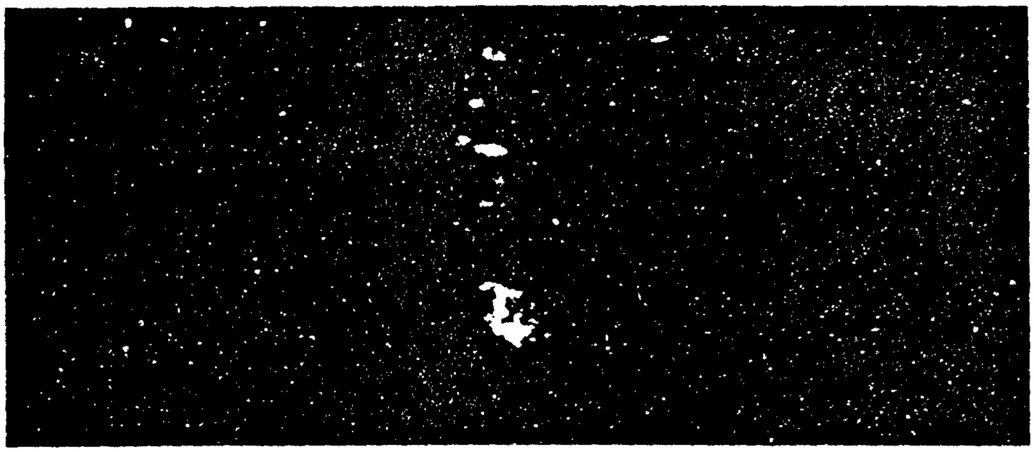

Fig. 32(a) — Interactive SAR example — nominal focus

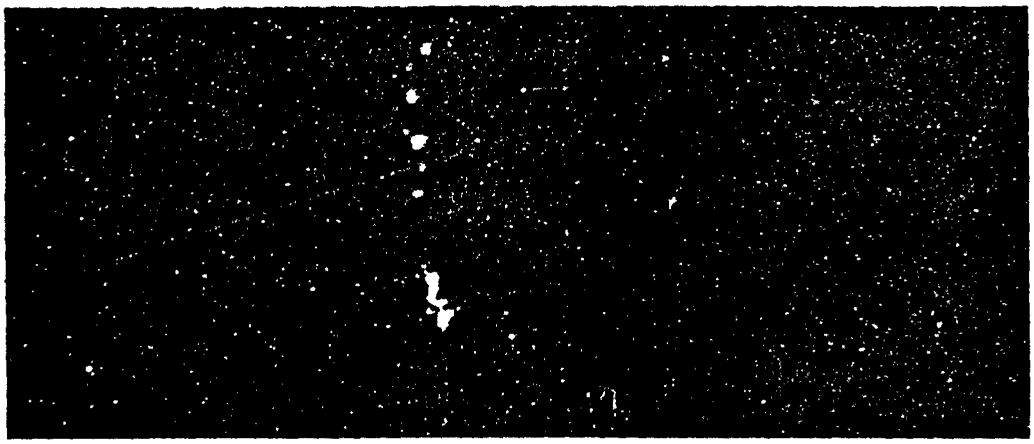

Fig. 32(b) — Interactive example - focus for left-rear

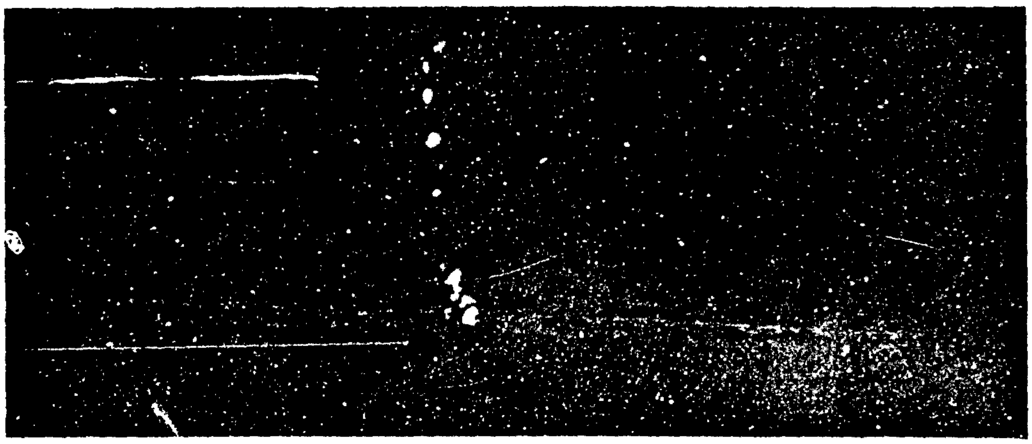

Fig. 32(c) — Interactive example - focus for right-rear

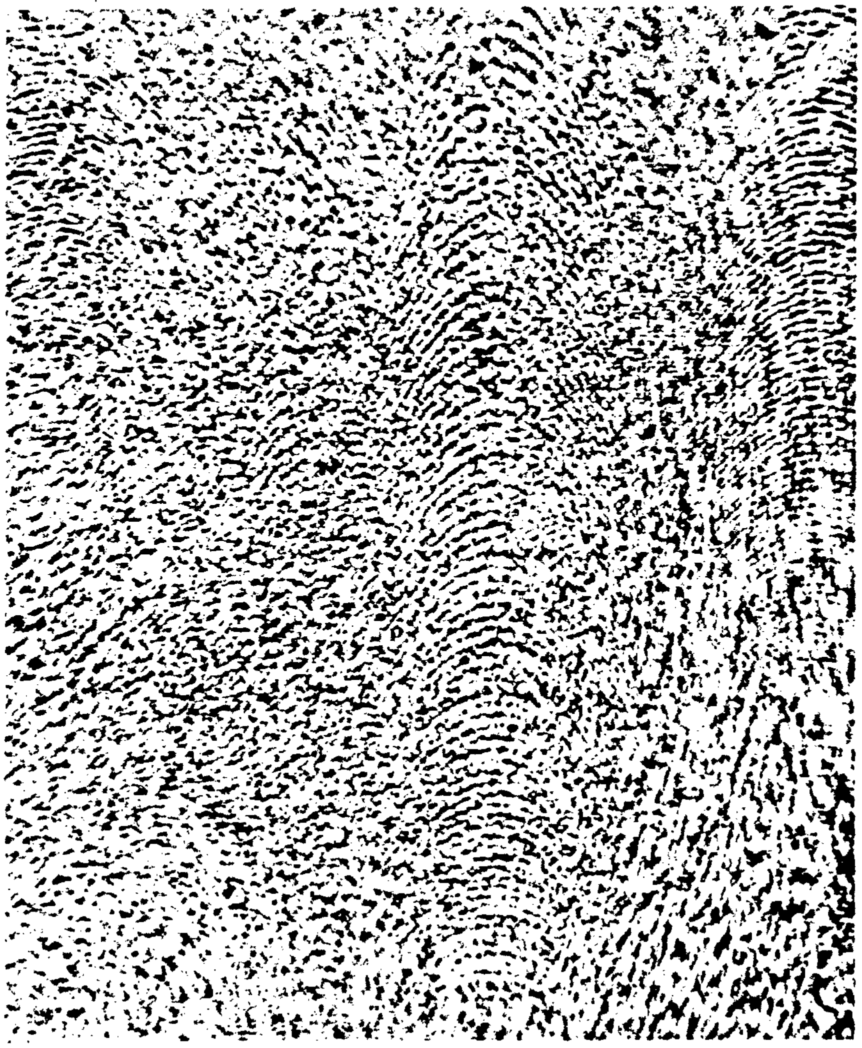

Fig. 33 — I-phase component of phase history from NRL airborne recorder

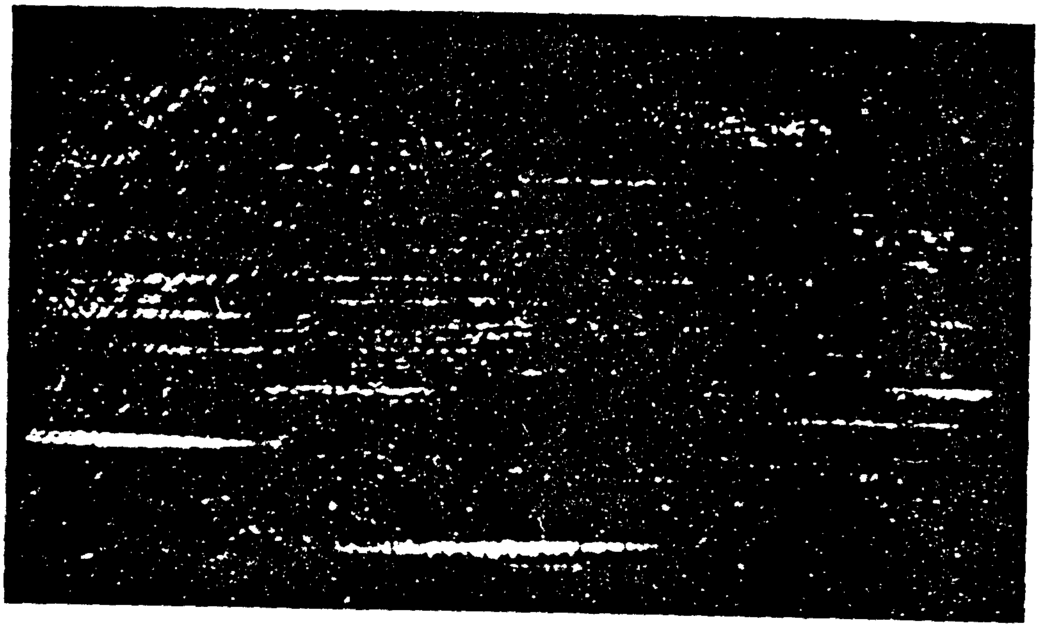

Fig. 34 — Range correlation of NRL recorder phase history

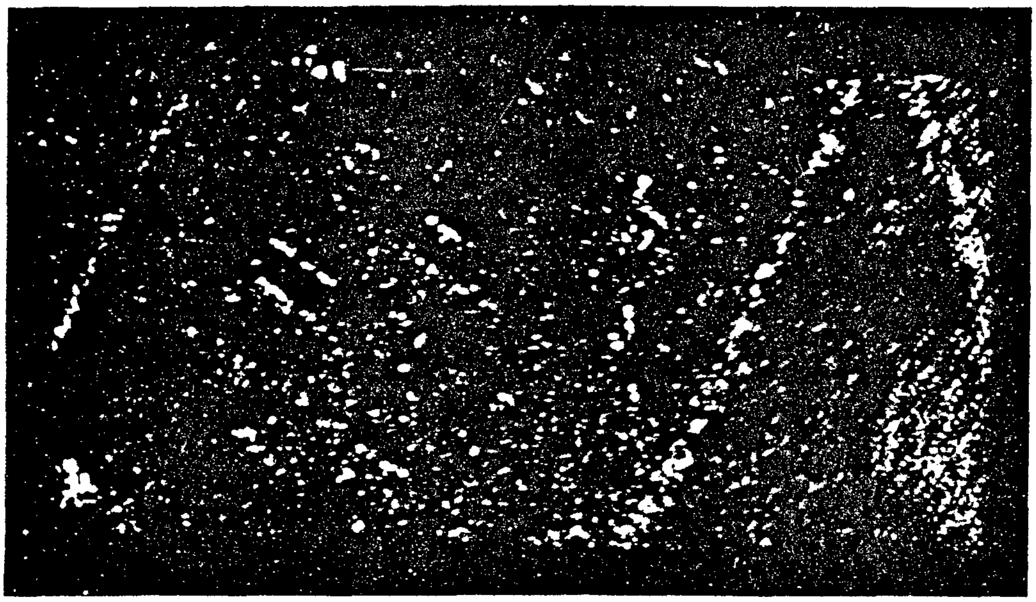

Fig. 35 — Complete correlation of NRL recorder phase history

the recorder can record and reproduce wideband data with coherency for SAR and pulse compression processing.

4.2 Dual-Mode Scanner in Aerial Image Mode

Figure 36 is a scan of the static correlator exit slit for the same phase history that was correlated digitally and shown in Fig. 32. The present figure was scanned in the logarithmic mode so the ship is completely outlined, and motion smear effects are clearly visible. After examining a number of SAR images scanned in the static correlator by the dual mode scanner, interpreters are convinced that essentially all the information available in the microscope is preserved in the scan.

4.3 Interactive Image Manipulation

It is difficult to give a typical example of an interactive system. This difficulty is especially acute with HIPS because differences in operators can lead to differences in the employment of the commands in HIPS. Nonetheless, a "typical" run will be traced using a piece of imagery on tape as the input to the system. Two other difficulties of description need to be mentioned. The display is usually operated in color while the figures are in black and white. The display, in color or black and white, has much greater detail visible than does film. Thus, the figures are only suggestive of the imagery as seen by the operator. Secondly, the operator will interact with the imagery, trying this, trying that, and choosing among the results. These differences are usually too subtle to be captured on film for reproduction here. It is important to emphasize, however, that the HIPS system allows a user to interact with the imagery in a trail-and-error fashion. The results of the interaction are not measured analytically but with human judgement.

The log and the associated figures trace a typical run. The display commands are not shown but are used in each step to put the imagery on the COMTAL display.

4.4 Printer Image Output

A secondary output device for the facility is the Versatec printer-plotter. While it is mainly used for hard-copy output for programming, it has an imaging mode using a special shading character set designed by NRL. Figure 46 shows the same ship as Fig. 26 reproduced by the printer. This mode is principally of value for precisely locating one pixel for detailed evaluation.

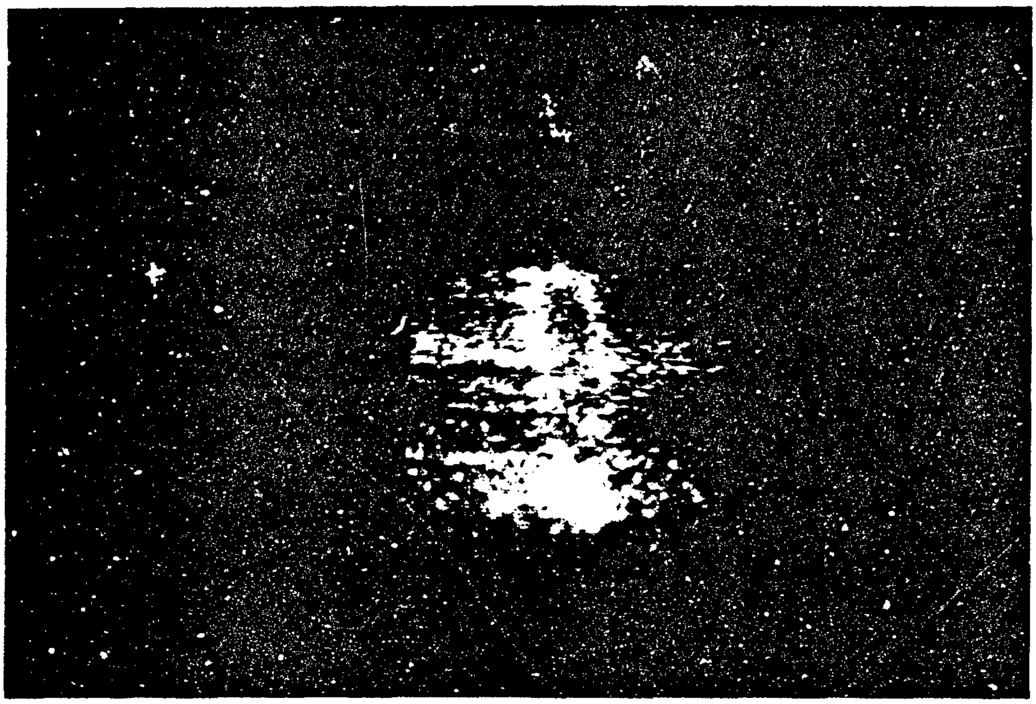

Fig. 36 — Result of dual mode scanner of ship in static correlator

HIPS DEMONSTRATION

Command/Response	Meaning/Parameters	Figures/Explanations
1. LR	Load raw image from tape	The parameters are designed to cope with the wide variety of tape formats. Also if extended images are on tape (longer than 1024 x 1024 pixels), the files and records skipped allow picking out a sub-portion.
Density	0 = 200, 1 = 556, 2 = 800 bpi	
Pack mode	0 = 6 bit, 1 = 16 bit, 2 = 12 bit word	
Files to skip	n	
Rec's to skip	n	
PE scan	yes/no	
2. FS Frame ?	Display the raw Image Full Screen which 512 x 512 block of the nominal 1024 x 1024 pixel images it to be displayed/processed.	Figure 37. The actual image is some 800 x 500 pixels in extent and is a radar image of the commerical pier in Long Beach. A large bulk carrier is in the lower center of the image running vertically. The structure running horizontally at the top is a bridge over the channel with its reflection from the water mirrored just below.
3. EX	EXtract a 100 x 100 block from the FS Images	Figure 38. The bulk carrier has been extracted with two 100 x 100 blocks using the simple eight bit map (7) transfer function. The bridge area has been extracted using the fold (6) transfer function and is the imagery at the top of Figure 38.
Transfer Function	1 = Piece-wise Linear 2 = Logarithmic 3 = Exponential 4 = Log-Exponential 5 = Linear Log Exponential 6 = Fold 200 x 200 into the 100 x 100 block 7 = Any eight bits	
4. FS Frame ?	Display the raw image Full Screen which quadrant of the nominal 1024 x 1024 image is to be shown	Figure 39. The display is 512 x 512 in extent; the same size as the image. The image is a 12 x 12 checkerboard of on/off values.

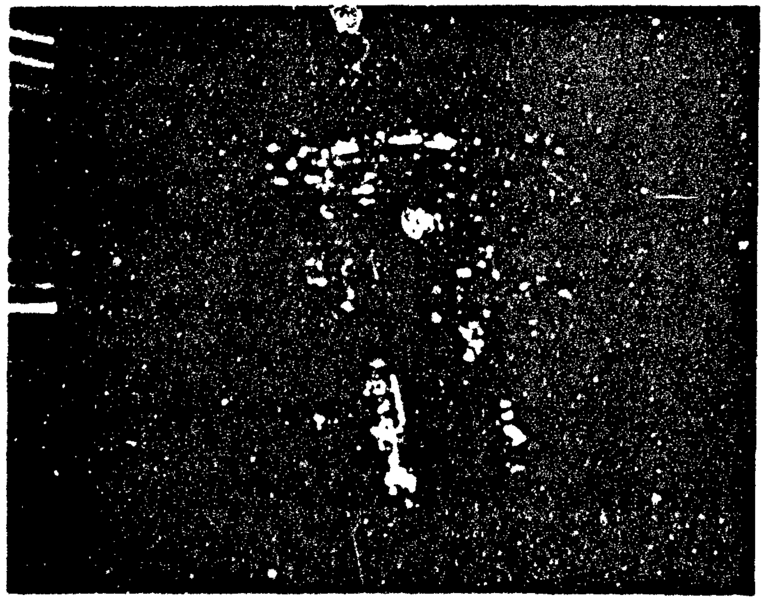

Fig. 37 — FS display

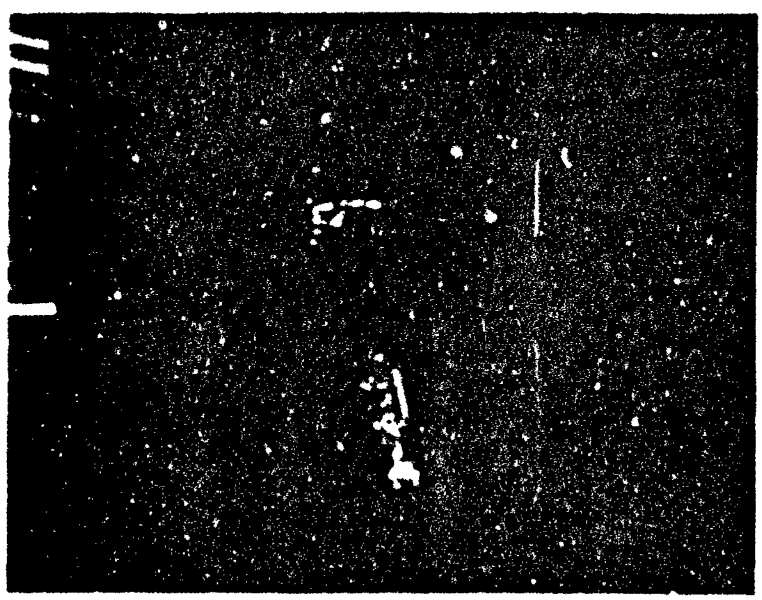

Fig. 38 — EX extraction display from FS image of Fig. 37

HIPS DEMONSTRATION - Cont'd

Command/Response	Meaning/Parameters	Figures/Explanations
5. EX Transfer function	Extract a 100 x 100 block 1 = Piece wise linear 2 = Logarithmic 3 = Exponential 4 = Log-Exponential 5 = Lin Log Exponential 6 = Fold 200 x 200 into 100 x 100 7 = Any eight bits	Figure 40. Three 100 x 100 sub-arrays of the full size image were extracted mapping the intensities from the full size array via the transfer function ordered. The 100 x 100 array is loaded into one of the HIPS buffers which are the basic working arrays. The operation from this point on will be with 100 x 100 arrays. In this particular example, the two upper extractions are with transfer function = 7, the lower transfer function 6.
6. RT Buffer = Buffer = Angle =	Rotate an image some angle θ Input image to be rotated. Output image stored in this buffer. Angle of rotation measured positive counter clockwise.	Figure 41. Typically, this command is used to line up images taken from slightly different geometries. The starting image is shown on top, the rotated image on the bottom. The pattern is a portion of the checkerboard of Figure 39.
7. TX(TY) Buffer = Buffer = Amount =	Translate in X(Y) Input image Output image Number of pixels to be translated	Figure 42. Purpose same as with RT. The starting image is upper left. Operation of TY = 16 is shown in upper right. TY = 24 is shown in lower left and cumulative TX = 24, TY = 16 is shown in lower right.
8. OV(02)	Overlay, Overlay by averaging Input images Output images	Figure 43. These two operations are used to combine pictures into one 100 x 100 array. The two modes are demonstrated with the Master and translated Master on the upper left and upper right respectively. OV performs a logical "OR" on intensities, 02 averages intensities as shown on the lower left and lower right respectively.

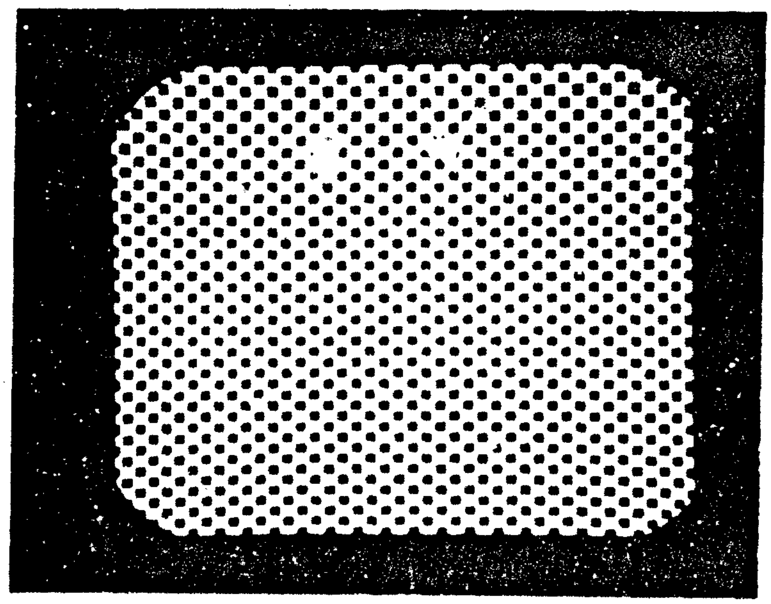

Fig. 39 — FS display of example imagery

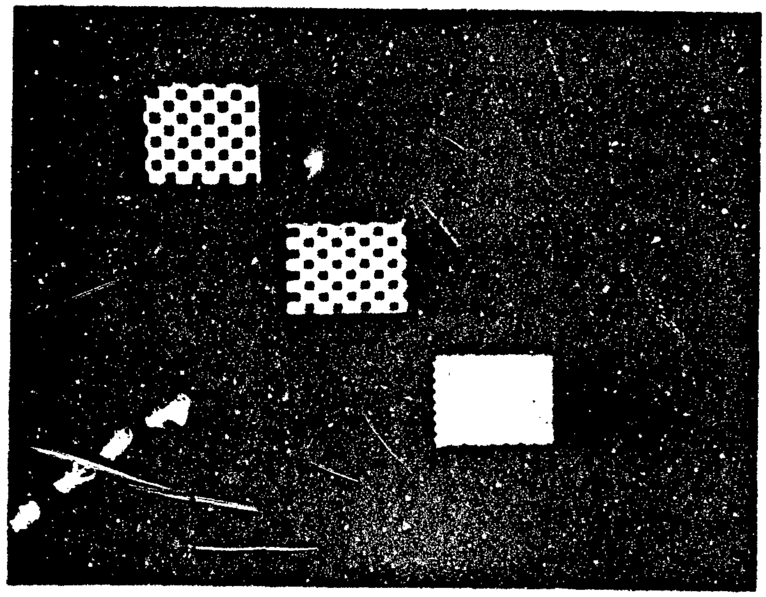

Fig. 40 — EX extractions from Fig. 39

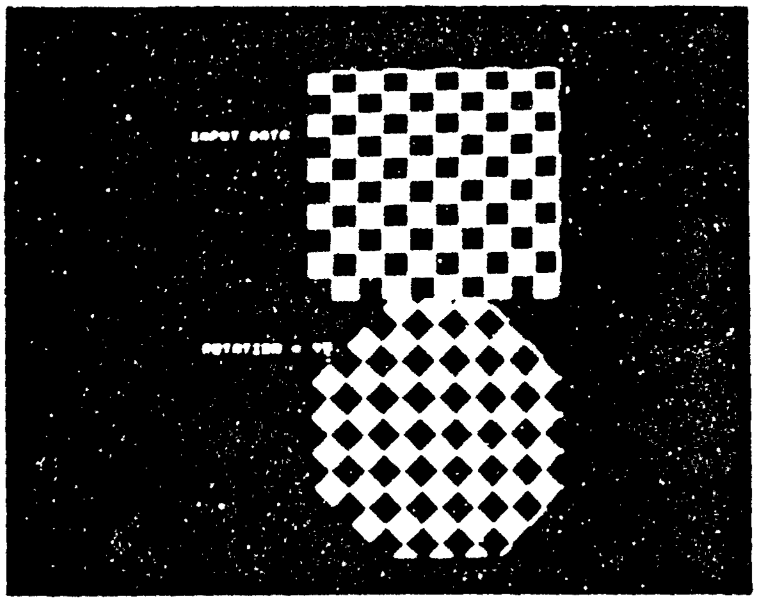

Fig. 41 — RT rotate command example

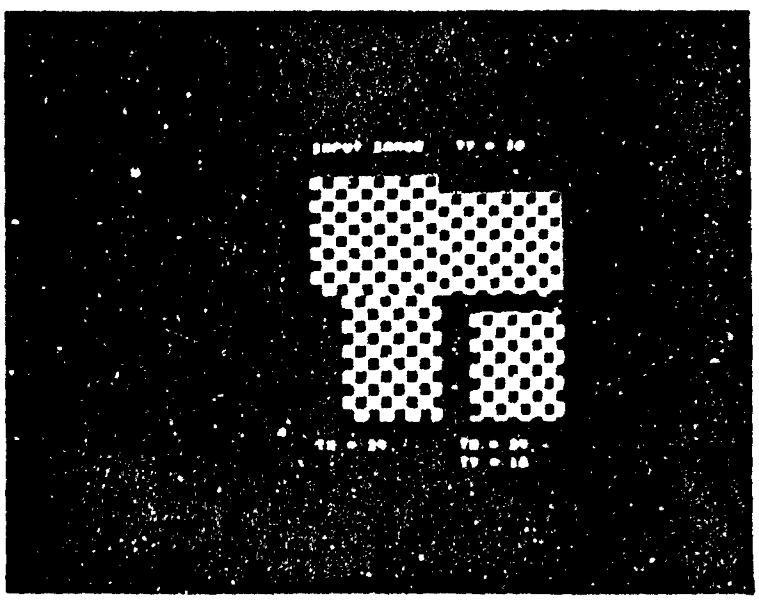

Fig. 42 — T_ translate command example

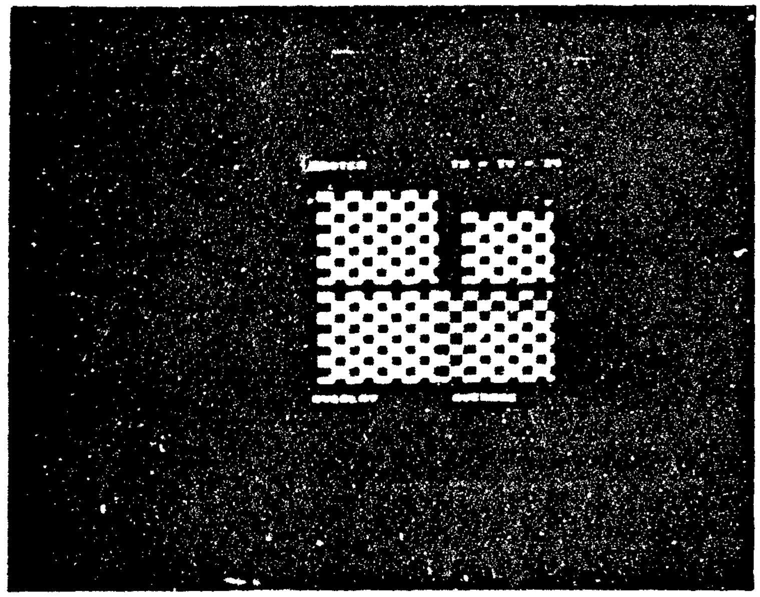

Fig. 43 — O_ overlay command examples

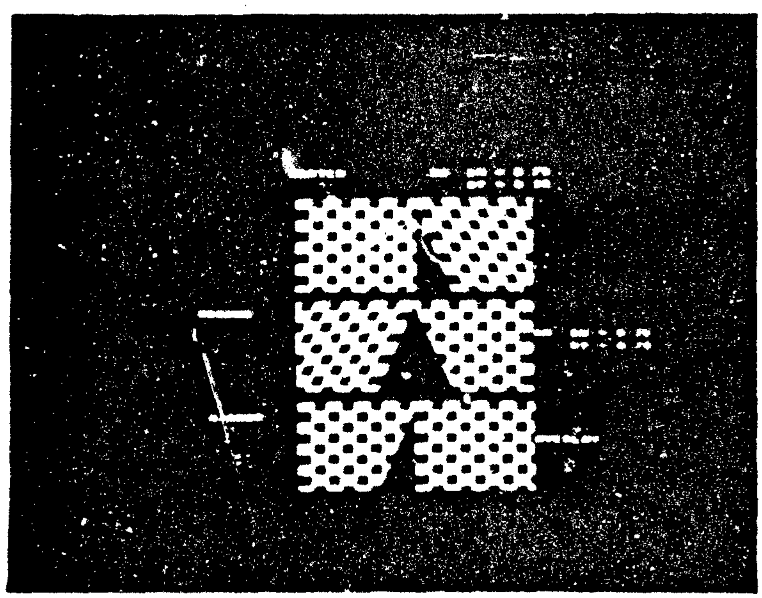

Fig. 44 — S_/MR shearing and mirror command examples

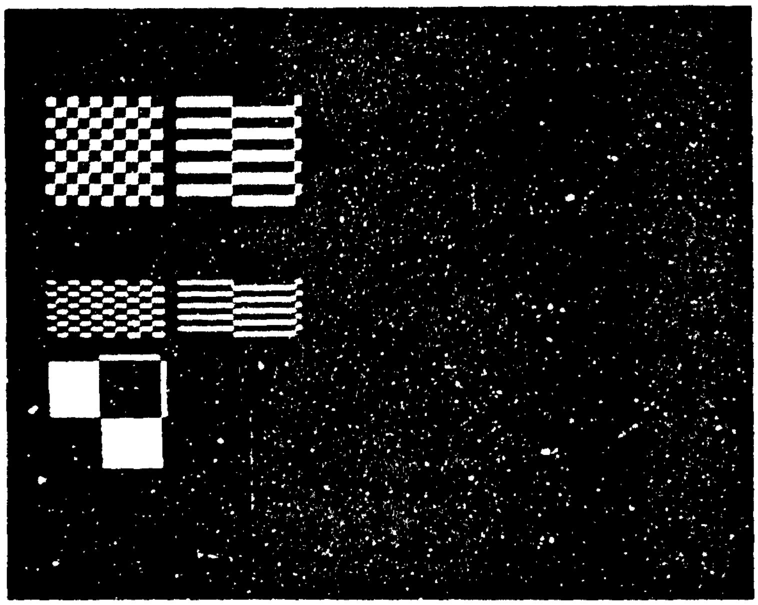

Fig. 45 — S_ scale command examples

HIPS DEMONSTRATION - Cont'd

Command/Response	Meaning/Parameters	Figures/Explanations
9. SH/MR Input buffer Output buffer ΔX = ΔY =	SHear and MIRror Input image Output image	Figure 44. The data is sheared along a line with slope $\Delta Y/\Delta X$ using the upper left point as the origin.
10. SC(SX,SY) Scale value = Input buffer = Output buffer =	Scale an image (in X,Y) Input image Output image	Figure 45. The purpose is the same as RT. Scaling means mapping a distance in the input image with a scale factor into the output image. In the figure, the upper right image is SX = 5; middle left is SY = 0.5; middle right is SX = 5, SY = 0.5; and SC = 5.
11. SD File name = PIC name =	Store on disk File name where to store image Picture name to be assigned this image within file Housekeeping data	Store processing results on disk
12. TM	Terminate	End HIPS run.

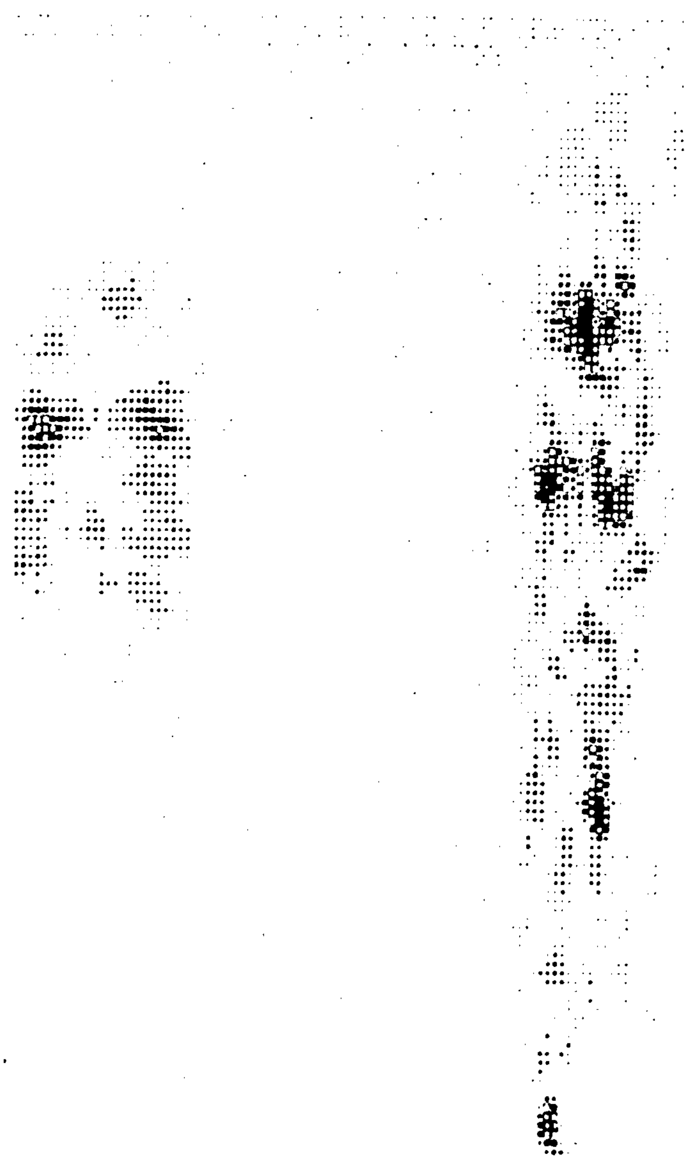

Fig. 46 — Printer imagery example

5. Acknowledgements

The authors would like to express their acknowledgement to all those who have contributed to the success of this program. David Drake and Frederick Sollner of NRL are commended for their efforts in making the dual-mode scanner a reliable and operational device. Benjamin Koo has been the individual who has been primarily responsible for the successful implementation of all the system software. Bruce Kremer of NRL is acknowledged for his efforts in developing and operating the wideband recorder and reformatter. Finally, the successful operation achieved to date would have been impossible without Victor Pocaro of NRL in the debugging and maintenance of the overall facility system hardware.

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SUBJ: Review of NRL Reports

Dear Sir/Madam:

Please review NRL Reports ~~7583~~, ~~7631~~, 7752, 7765, and MR-3079 for:

- ☑ Possible Distribution Statement
- ☐ Possible Change in Classification

Thank you,

Mary Templeman

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The subject report can be:

- ☑ Changed to Distribution A (Unlimited) for Reports 3079, 7765, and 7752
- ☐ Changed to Classification ________
- ☑ Other: Reports 7583 and 7631 should retain there limited distribution statements

Paul K. Hughes II 8/21/2002

Signature Date

-- 1 OF 1
-- 1 - AD NUMBER: C003096
-- 2 - FIELDS AND GROUPS: 12/6, 17/9
-- 5 - CORPORATE AUTHOR: NAVAL RESEARCH LAB WASHINGTON D C
-- 6 - UNCLASSIFIED TITLE: INTERPRETATION FACILITY FOR SYNTHETIC
-- APERTURE RADAR.
-- 9 - DESCRIPTIVE NOTE: FINAL REPT.,
--10 - PERSONAL AUTHORS: KERR,DAVID W. ;HERMANN,GEORGE W. ;TAMNY,MICHAEL A.
-- ;
--11 - REPORT DATE: JUL 1975
--12 - PAGINATION: 90P MEDIA COST: $ 7.00 PRICE CODE: AA
--14 - REPORT NUMBER: NRL-MR-3079
--16 - PROJECT NUMBER: A370-370D/058-B/4F12-111-704, NRL-R02-46
--20 - REPORT CLASSIFICATION: UNCLASSIFIED
--22 - LIMITATIONS (ALPHA): DISTRIBUTION: FURTHER DISSEMINATION ONLY AS
-- DIRECTED BY CONTROLLING DOD OFFICE, OR HIGHER DOD AUTHORITY.
--23 - DESCRIPTORS: (*SYNTHETIC APERTURE RADAR, *IMAGE PROCESSING),
-- (*RADAR IMAGES, IMAGE PROCESSING), MILITARY FACILITIES, DATA
-- ACQUISITION, DATA PROCESSING, DIGITAL SYSTEMS, DIGITAL RECORDING
-- SYSTEMS, DIGITIZERS, MINICOMPUTERS, TELEVISION DISPLAY SYSTEMS
--24 - DESCRIPTOR CLASSIFICATION: UNCLASSIFIED

--END << ENTER NEXT COMMAND >> END --